RECENT DEVELOPMENTS IN THE MEASUREMENT AND CONTROL OF SURFACE ROUGHNESS.

Paper presented to the Institution, Birmingham, Birmingham Graduate, Coventry, Eastern Counties, Edinburgh, Glasgow, London, Southern, and Western Sections, by Harry Shaw, Grad. I.P.E.

PROGRESS in the useful arts might almost be said to consist in the applying of science to the art. Indeed the quondam artist has in many instances become but a labourer applying methods devised by science.

In the manufacture of a casting the exact mixture and treatment to give a desired result is controlled by science, the heat measurement involved being made by precise pyrometers working on scientific principles instead of by the eye of an artisan. In the preparation of the mould in some instances a certain amount of art still remains, but even this is gradually being superseded by science as knowledge is accumulated.

Precise measurement and control is applied in almost all branches of the useful arts. Working clearances are set within limits by making the parts to definite tolerances.

Despite this, very little has been done in the way of controlling the finish that shall be given to the working parts, beyond the specification by such terms as "rough turn" and "polish," the interpretation of which depends upon the workman.

Has this lack of specification been due to the absence of means for determining the degree of roughness of surfaces, or has the absence of the means for testing rendered it impossible to detect the great influence of finish on functioning, and so the need for specifying finish not appreciated ?

The writer believes the latter and that the absence of means for precisely recording the change in the roughness of surfaces under different conditions has prevented the effect of finish on wear, friction and corrosion from being properly observed. Moreover it has not been possible to detect properly whether one method of

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finishing a surface really gives a smoother finish than another, for visual examination is by no means reliable.

Fig. 1.

The sample system of finish specification

Various methods of observing surface roughness.

One of the earliest attempts at controlling surface finish was made by a firm in the United States who mounted samples of finishes produced by different methods in cases (Fig. 1) which were supplied to the workman, who was expected to get a finish on his work as near to that specified as possible. While quite suitable as a method of controlling finish from the point of view of appearance, the method does not in any way indicate the degree of the roughness.

Harrison, of Cincinetti Grinders, devised a method of calibration in which a sapphire needle attached to a pick-up arm, as used in radiograms, is dragged across the surface to be tested, the vibration so produced giving rise to sound in a speaker, and variation in the current reading on a millivoltmeter (Fig. 2). The sound and current reading obtained from a piece of work is compared with that from a sample having the finish supposed to have been given to the work.

While this system may be convenient for comparing finishes, it does not depict the actual degree of roughness and it is difficult to see how there is any gain in replacing the judgment of the surface by sight with the judgment from the sound given by the testing. The amplitude of the current reading will, it is thought, bear a greater relation to the pitch of the roughness than to the depth. Speed of motion of the sapphire point and the frequency response of the pick-up and amplifier will influence the results. It is necessary to find the shape and extent of the surface roughness by some other method before the current reading has any significance. The method cannot indicate departure from flatness.

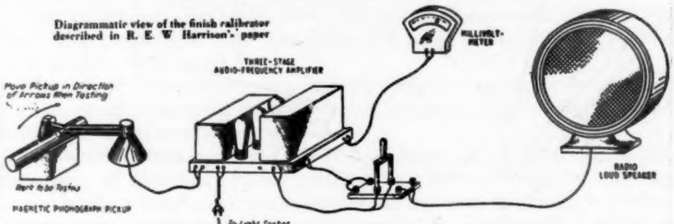

Fig. 2.
The Harrison finish calibrator.

The examination of surfaces under the microscope may be means of comparing surfaces but does not enable the exact shape or depth of the roughnesses to be determined.

The examination of sections of a surface under the microscope, even if the surface be set in another material, suffers from the slowness of the process, and from the error caused by distortion of the surface by the sectioning. The work is destroyed by this method.

The bending of plastic casts (Figs. 3-1) taken from the surface over knife edges so that the contour can be examined under the microscope or projected on to a screen suffers from the errors in taking the cast and from the distortion of the cast during the bending. This method has the advantage that it does not destroy the work being examined.

To obtain a measure of the depth of the roughnesses in a surface, a method of lapping the roughnesses away and taking readings of the amount lapped away before the bottom of the roughness is reached is sometimes employed (Fig. 3-3), but is very slow and expensive and destroys the work.

Another method giving comparative results is that in which a beam of light reflected from the surface is allowed to fall on a screen. The rougher the surface the greater is the diffusion of the light (Fig. 3-2). Oil and colloidal matter on the surface falsifies the results. Indeed, in *Deutsche Motor-Zeitschrift* (page 134, Heft,

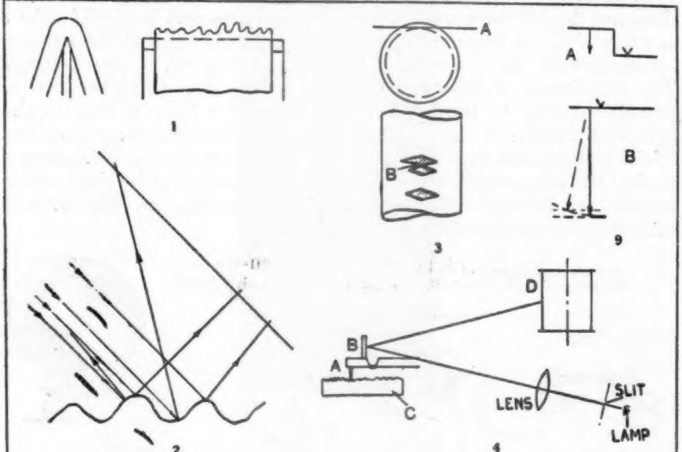

Fig. 3.

(1) Bending a plastic cast taken from a surface will reveal the surface roughness. (2) The degree of diffusion of light from a surface indicates the roughness. (3) By lapping the roughness away its depth can be found. (4) The Profilograph of the University of Michigan. (9A) The position of the tracer point and pivot in the Contorograph and (B) in the ultra-Contorograph.

7/1933), the writer described how this method can be used for detecting the presence of colloidal matter in the pores of metal of like finishes.

A method of interest but of little practical value for the workshop relies upon the principle of focussing, a point of light being projected

on to the surface and viewed through a microscope, the work being "racked" in or out so as to bring the point of light into focus as this falls upon the tops, sides, or bottoms of the roughnesses. The racking movement is recorded so giving a record of the surface. In a variation of this system the work is stationary and the microscope and projection apparatus is moved to focus the light. This method can only be used on very rough surfaces.

Carl Zeiss market a microscope, designed by Prof. Schmaltz, for the examination of surfaces, in which a sheet of light is projected on to the surface at an angle so that, looking through the microscope, inclined to the surface, the viewer sees a bright line following the contour of the metal. This is the most practical microscopic method devised.

Necessity for False Scale.

With all the methods so far described, but a small portion of the surface can be examined, for the roughness is magnified equally in all directions.

To get a true picture of the roughness we need to examine at least half an inch of surface, for most finishing processes are such that the roughness varies considerably in a short length.

Road contours are a good analogy, for it is obvious that we could not use a road contour map if this were drawn to the same scale in both directions. If to measure the small defects in certain surfaces it is necessary to use a magnification of 2,000, and to get a good idea of the average roughness it is necessary to examine half inch of surface, the length of the record would be 1,000 in. (90 feet) and as the roughness might be but, say, a ten-thousandth part of an inch, this magnified 2,000 times (to 0.2 inch) would not be visible in a length such as 90 ft.

The writer therefore maintains that any instrument for measuring surface roughness must give a greater magnification to the vertical roughness than to the length.

One such instrument is that of Willy Kieswetter of the Engineering Academy of Dresden. In his instrument a needle rising and falling in the surface roughness oscillates a lever one end of which scratches a smoked glass. The glass must be accurately positioned in relation to the movement of the lever, otherwise the resistance between the stylus and the glass will cause detrimental pressure on the work. In a similar instrument the lever forms one plate of a condenser, so that as the gap in the condenser varies with the movement of the needle the current capacity varies. Electrical measurement and recording on an oscillograph of the current capacity gives a curve that pictures to some scale the surface roughness. Unfortunately the type and size of material being examined affects the reading, seemingly by influencing the condenser. Metals containing free

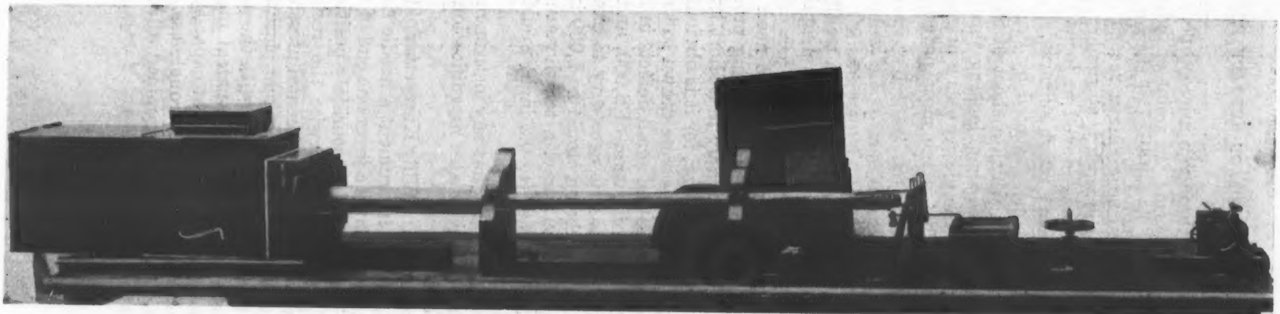

Fig. 4.
General view of the experimental Contorograph

graphite were found to produce readings in no way conforming to the actual surface.

Another instrument in which a needle is employed is the profilograph of the University of Michigan (Fig. 3-4), in which the rise and fall of the needle causes a mirror to oscillate so that a beam of light falling on it is deflected up and down on a piece of sensitised paper attached to a drum revolving at constant speed.

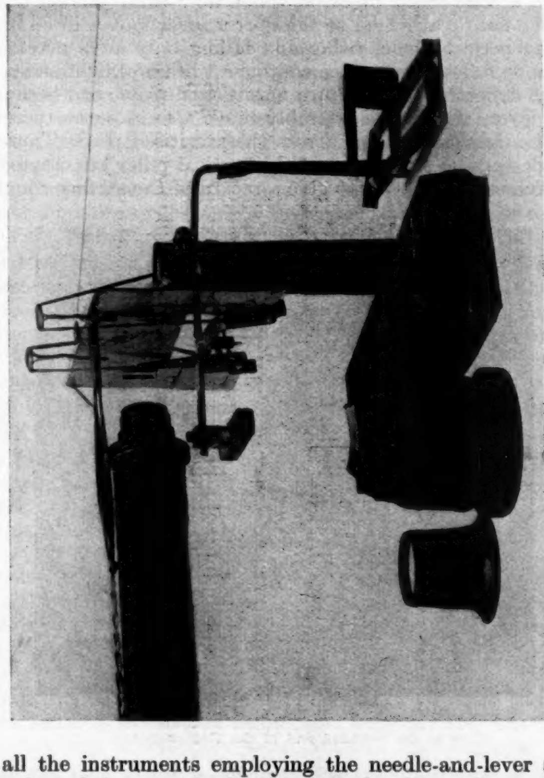

Fig. 5.
The pillar and arm assembly of the experimental Contorograph.

In all the instruments employing the needle-and-lever system, the specimen being examined is drawn under the needle on accurate slideways, ways which must be absolutely accurate, for any error in them will be magnified to the same extent as the variations in the surface roughness and so be superimposed on the errors in the surface being examined.

The difficulty of producing accurate ways and keeping them in order in the average works will be appreciated, particularly if the ways have to carry large work as, say, a cylinder block.

Realising this and the impossibility of using such instruments where vibration cannot be eliminated the writer designed and made an instrument called the "Contorograph" (Fig. 4 and 5).

In this instrument a vertical pillar (Fig. 5) carries a cross arm to which is attached a lever and mirror assembly. As the pillar turns on a cone-ended pivot on which no "cam" action can take place, the needle attached to the mirror lever moves in an arc of a circle in a perfect plane, rising and falling only as is necessary to enable it to follow the surface contour. A beam of light striking the mirror is deflected up and down a sensitised plate, and because the mirror, lever, and needle assembly move also in an arc across the work, the light also passes across the sensitised plate. Thus, from the single turning movement of the vertical pillar are created both the movements necessary to give a record of the surface roughness.

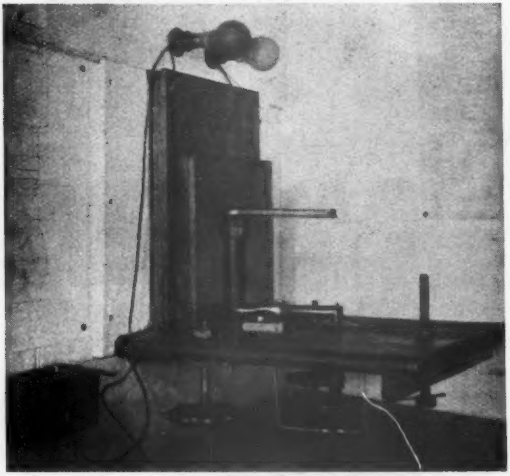

Fig. 6.
View of the working end of the Contorograph.

It will be seen that in this instrument accuracy does not depend upon ways but upon the almost perfect action of a flat surface upon a conical pivot that cannot easily become inaccurate. Nor is there need for synchronisation of the movement of a needle across a surface with the turning movement of a drum as in other similar

instruments, a difficult problem in view of the variation of the resistance to motion of the work under the needle.

Temperature variation normally being slow does not affect readings, particularly as only movement between the work and the needle is magnified. Movement of the optical projection system is not magnified.

When curved work is being examined, allowance must be made for the needle moving in a circular path. On work of large curvature this can be ignored.

To prevent the needle from dropping suddenly into deep pits, causing vibration of the apparatus as the needle rebounds from the bottom of the pit, hence falsification of the record ; also to prevent outside vibration from affecting the instrument, the needle lever is "dashpotted." The dashpot is so constructed as to prevent excessive pressure from being imposed on the needle, and is so effective that a sharp blow struck on the instrument causes but two oscillations of the mirror before its effect is entirely damped.

To enable surfaces to be examined more quickly and to allow of cylinders being tested without the cylinder being broken up an instrument employing the same principle of operation has been constructed. The vertical pillar of the experimental contorograph is cranked (Fig. 6) so that a bore can be entered and the cylinder is mounted on a plate that rests on three screws. Adjustment of the surface to be tested up to the tracer point is effected by manipulating the three screws.

The optical projection system is entirely enclosed so that the instrument can be used in the light, though for convenience the back end of the writer's instrument passes into a dark room to enable the films to be extracted and developed immediately. One of the lamps at the top of the instrument acts as a tell-tale light and acts as a resistance to reduce the mains voltage to a 3.5 spot light bulb that is the light source, while the other lamp is a tell-tale in the circuit of an electric motor that draws the cranked arm round. The motor is in the box at the extreme bottom left of the illustration.

The projector light and motor come into and go out of action automatically as the contorograph operates.

Work ranging from small samples to large car and bus cylinder blocks has been successfully tested on this contorograph.

The reliability of the instrument may be judged from the four contorograms of Fig. 8 taken from the same spot on a surface. There is very little difference between the records. When it is considered that the variation is due to the following combined causes, it will be realised that during any one test the effect of such will be negligible.

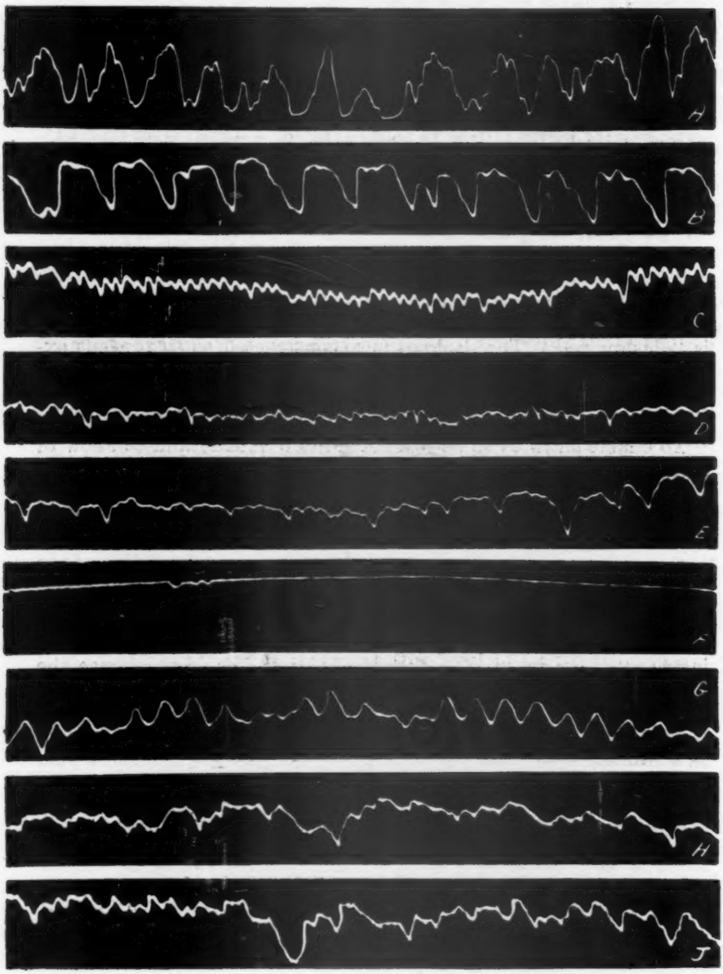

Fig. 7.

Contorograms (vertical magnification 1,400, horizontal 22) of : (A) Fine turned surface on cast iron. (B) Face turning on cast iron. (C) Krause type fine-boring on cast iron. (D) Ground cast iron. (E) Honed surface in which the signs of the boring still show. (F) Mirror finish honed surface. (G) Drawn brass fine turned. (H) Drawn brass ground. (J) Grinding on cast bronze.

The difference can be due to:

(*a*) Tracer point wear;
(*b*) wearing of the surface by the tracer point;
(*c*) errors in the positioning of the specimen, causing the tracer point to pass over a slightly different path each time;
(*d*) expansion or contraction of the surface due to temperature variation between one test and another;
(*e*) vibration;
(*f*) removal of dirt or loose material by the tracer point;
(*g*) variation in the warping or contraction of the films;
(*h*) errors in the instrument.

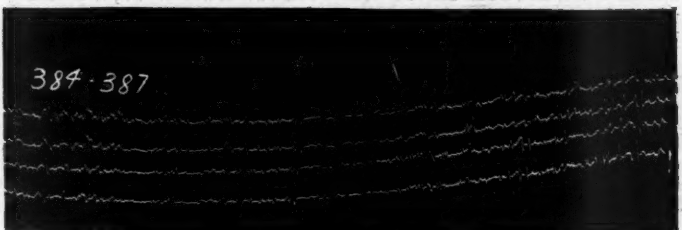

Fig. 8.

Four repeat tests on a surface show the absence of errors in the Contorograph.

To obtain a true reproduction of the shape of the roughness the tracer point should be level with the pivot at Fig. 3-9a. If mounted below the pivot a greater magnification is obtained but the shape of the roughness is not correct.

Specification of Surface Finish.

It is not sufficient when specifying finish merely to state the maximum depth of the roughness in, say, millionths of an inch, for by such a system it is quite possible for two entirely different surfaces from the point of view of load bearing capacity to conform to the same specification. For instance a very rough surface might bear the same specification as a smooth honed surface in which there are occasional deep fissures where the original boring marks have not been removed, and it is obvious that the latter type of surface would be much better as a bearing surface.

To define surface finish completely, the percentage of the area that will bear pressure after definite amounts of wear have taken place should be stated, in addition to the total depth.

Thus the specification for a rough bored finish would read:

Total depth of roughness 500 microinches (millionths):

After	50 microinches	wear	5%	of the	area	must	make	contact
,,	200	,,	,, 20%		,,	,,		,,
,,	300	,,	,, 50%		,,	,,		,,
,,	400	,,	,, 80%		,,	,,		,,

or in the "Shaw surface-finish specification system," the specification would read: Rough bore, 500—50/5%, 200/20%, 300/50%, 400/80%.

As in workshop practice it is not feasible to keep to such a complex specification it is sufficient to specify the total depth and the area that must come into contact after one amount of wear, so the above specification can be abbreviated to a form such as follows, depending upon the purpose or conditions for which the surface is required: Rough bore, 500—50/5%. Rough bore, 500—300/30%.

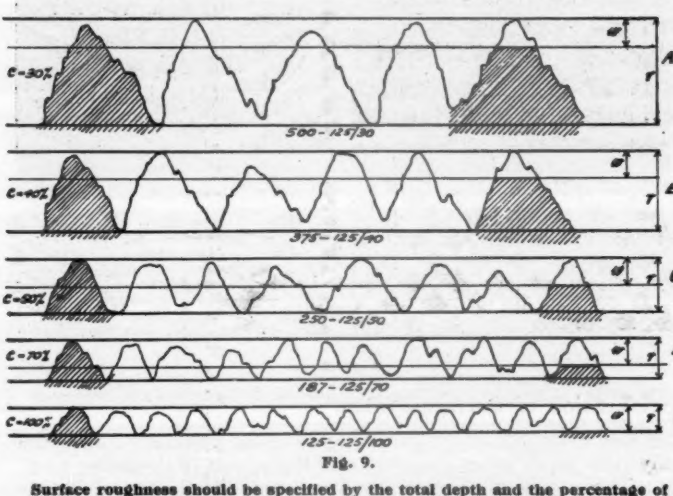

Fig. 9.

Surface roughness should be specified by the total depth and the percentage of area that will come into contact after a definite amount of wear.

Thus, in Fig. 9 the surface roughness at *A* has a depth of 500 microinches while after a depth of wear *w* of 125 microinches 30 per cent. of the surface will be in contact, while at *E* the depth is 125 microinches so that after 125 microinches' wear the whole of the surface will be in contact.

In specifying, and working to a specification, it must be borne in mind that different processes produce different surfaces. For instance, planing, turning, boring or peripheral grinding produces

ridges or parallel furrows, so that the area in contact bears the same relation to the total area that the width of the hills bears to the width across both hills and valleys.

In face milling or grinding with a cup wheel, when the cutter or wheel marks cross, the area in contact is rather difficult to determine and varies with the relation the feeds bear to one another.

Where cutting or grinding marks cross as in honing the percentage of the area in contact is equal to the square of the percentage in contact in one direction.

Thus, if one-fifth (20 per cent.) of the surface will make contact when measured in a contorograph record, $1/5^2$ that is 1/25 equalling four per cent. will make contact when a similar record is obtained in a direction normal to the direction of the first record.

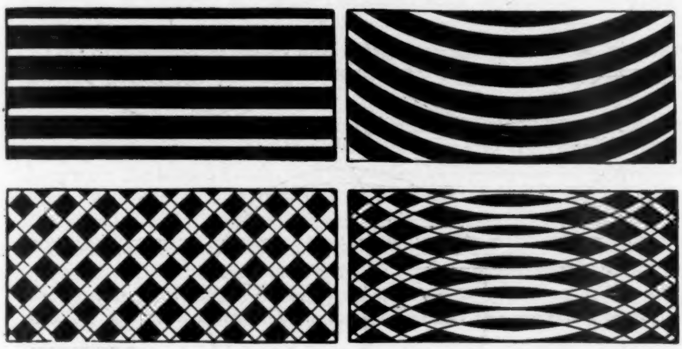

Fig. 10.

The method of production of a surface influences the pattern of the roughness.

If two records taken at right angles to one another on a surface truly pictured the average character of the surface in those directions, then the percentage of area in contact is equal to the product of the percentages of contact applying to the two sets of linear tests.

When the character varies considerably the average contact percentage should be determined by making several contorograph tests before the proper area of contact can be found, being the product of the average percentages so obtained.

Methods of Producing Surfaces.

In the earlier days of machinery building it was considered sufficient to finish shafts or journals by filing in the lathe and the

only finish thought of for bearings was boring or reaming. Later, as greater accuracy and durability at the higher speeds became necessary, lapping came into vogue.

Later, still as we know, grinding came into ever-increasing use for the production of both journals and bearings. For the production of bores, particularly when their surface was interrupted by ports or other openings, as in a cylinder, grinding or boring in the past

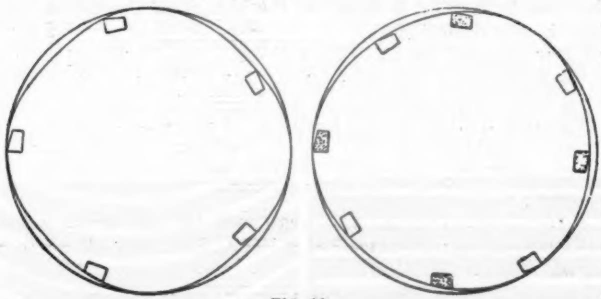

Fig. 11.

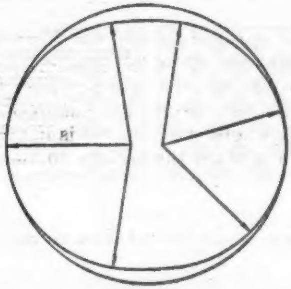

Fig. 11a.

Lobed bores that can be produced or maintained by four and five stone hones and an oval bore that cannot be produced by honing.

was not altogether satisfactory, for the grinding and boring spindles were by no means as rigid as was desirable, particularly when a comparatively long bore had to be entered. Indeed, the production of a truly parallel accurate bore was something of an art on the part the workman.

Honing machine makers in their propaganda very recklessly said that it was geometrically impossible for the honing process to produce an unround bore, and to prove their case they illustrated elliptical bores.

In a series of articles entitled "An Analysis of the Three-point and Multi-point Gauge" in the *American Machinist* (Vol. 75) the writer demonstrated the previously unknown fact that it is possible for any number of points equally or unequally spaced in a circle to fit in all possible positions in some unround or lobed bores, a fact that explains why parts that individually measure up correctly often do not assemble with the proper clearance.

In a later series of articles in *Machinery* on "Honing" (Vol. 40, 41) the writer showed how for the same reason the honing process could produce unround bores, particularly if some part of the machine were out of balance giving rise to loaded float of the hone; that is, float by pressure.

For a considerable time this lobing of bores was not known to exist, as it could not be detected by ordinary measurement, and was not sufficient to cause trouble with comparatively large clearances.

The fine-boring process was originated for producing accurate parallel bores, the machines being very rigid, and all parts well balanced.

Some automobile manufacturers who adopted fine-boring for their cylinders found that the wear was less and the running better than with the honed finish, and presumed this to be due to a smoother finish, whereas in fact it was due to the more accurate bore, the fine-bored finish if anything being not so good as the honed finish.

When round piston rings fit in a lobed bore they wear rapidly, allow blow-by and cause excessive oil consumption; and should the lobing spiral down the bore, great stress is imposed upon the rings as they try to accommodate themselves to the bore by changing their shape.

The Characteristics of Different Finishes.

The advantage of fine-boring is that it produces an accurate cylindrical bore, but the surface produced is spiky. The honed surface is better than the fine-bored but care should be taken to remove all boring marks, otherwise the surface will be broken up here and there with deep fissures.

The smoothest possible finish that can commercially be given to bores is by the mirror-finish honing process. The mirror-finish hone (Micromatic) is fitted with stones of very fine grit, and between the stones are non-abrasive guides which are pressed into contact with the bore to prevent scratching of the bore as the hone is withdrawn and vibration. Actually, the non-abrasive guides are mounted on resilient cork backings, these giving the necessary pressure to the guides.

The writer recommends that fine-boring should be employed to give parallelism and roundness and then mirror-finish honing for a good finish.

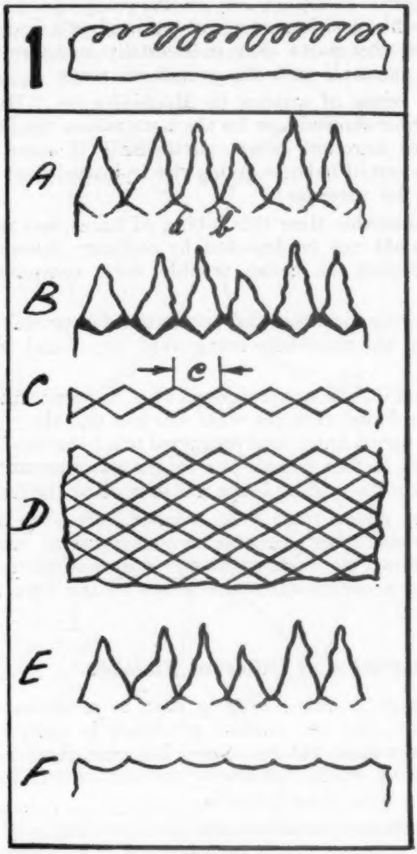

Fig. 12.

(Top) Burnishing may produce a porous under surface. (Bottom) The effect of corrosion on a rough surface.

The process of burnishing should be avoided unless the surface finish before burnishing is good, for burnishing merely rolls the hills over, producing a porous under-surface with a polished top. Such a surface soon breaks down if corrosion is present.

The Effect of Roughness on Wear.

The action of two surfaces in running contact must now be imagined. As the surfaces are at rest they are in metal-to-metal contact or separated but by adsorbed oil. As motion starts they become separated by greasy films and then as speed still further increases, sufficient oil is drawn in to separate the surfaces by a full film of oil. The coefficient of friction falls as the speed increases, up to a point at which increase in speed causes increased shear in the oil, when the coefficient of friction begins to rise.

So long as a complete oil film exists surface roughness does not greatly influence the wear, but actually a complete oil film is never maintained for any length of time, for the imposition of sudden or excessive loads breaks the oil film, and the surfaces then make metal-to-metal contact. When this occurs the rough surfaces have harsh contact giving rise to friction which heats and lowers the viscosity of the oil, when it is still less able to withstand the load, so the surfaces will make still harsher contact until, ultimately, the surfaces " pick- up " or seize.

As it is the roughness of the surface that initially, by increasing the unit load on the oil film at the peaks of the surface, contributes to the breaking of the oil film, the aim should be to produce the smoothest possible surface but also to reduce the friction when the surfaces contact. This can be done by adding running-in compound containing colloidal graphite to the lubricating oil, when graphoid surfaces will be formed on the metal surfaces.

(Colloidal graphite is prepared from pure graphite formed in the electric furnace at a high temperature, the graphite being colloidalised by various processes until it becomes evenly dispersed in an oil vehicle as a colloid, that is in the form of extremely small particles, invisible even under the microscope.)

The graphoid surfaces formed on the surface induce the oil to spread more readily so that broken oil films will more readily re-form, and the graphoid surfaces, being in themselves highly lubricant rub together with little fricition when the oil film is broken, hence little heat is generated to reduce the viscosity of the oil. Friction being reduced, so is the tendency for the surfaces to roughen.

While we should aim at producing the smoothest possible surface commercially possible, as our object is to reduce wear and friction arising through roughness we should aim at treating these surfaces in such a way that although we cannot obtain extremely smooth surfaces, the surfaces we do obtain will function as if they were smoother than they are.

This can be done by introducing lubricity to the surfaces during their production by adding materials that will impart this property to the cutting coolants. The addition of oil alone gives a certain

degree of lubricity, but the lubricity is far greater and more permanent if the oil contains colloidal graphite, for the graphoid surfaces formed are highly lubricant and absorb oil.

What is also important is that the oil or the colloidal graphite, by lubricating the non-cutting face of the tool or abrasive grains of, say, grinding wheels or honing stones, reducing the sticking of the cuttings in their passage over the non-cutting face, results in the production of smoother surfaces. For the same reason the non-cutting surfaces of the cutting-carbide tools are highly polished.

When the surfaces receive lubricity during production they do not tend to seize so much during running and therefore become stabilised or run-in much more quickly. Indeed one concern who add colloidal graphited oil to the paraffin used during the honing of cylinders during reconditioning find their engines much freer from seizure and much smoother running.

This lubricity should also be applied during running by adding colloidal graphite to the lubricating oil, if the initial clearances are to be best retained and the working surfaces are to take on a smooth glass-like appearance.

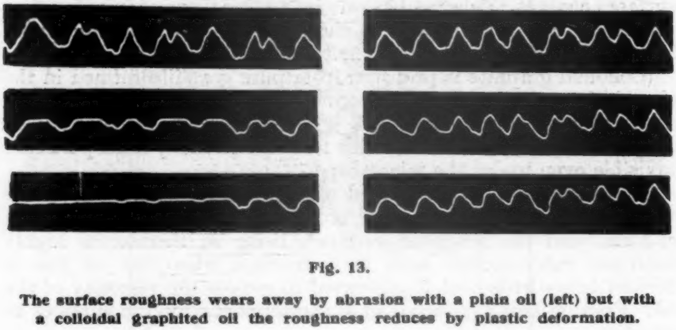

Fig. 13.

The surface roughness wears away by abrasion with a plain oil (left) but with a colloidal graphited oil the roughness reduces by plastic deformation.

When lubrication is by plain oil, wear takes place by an actual rubbing away of the surface roughnesses, whereas when the surfaces are treated with colloidal graphite their roughness is reduced by a plastic deformation rather than by attrition. Because of this, the surfaces become very dense taking on the glass-like appearance that results from smooth running, though as a consequence it takes longer for the surface to attain to a moderate degree of smoothness, though ultimately they will attain to greater smoothness.

Corrosion.

When corrosion is to be considered, roughness and surface treatment are of great importance. Corrosion occurs in the cylinders of internal combustion engines where the corrosive products of combustion condense upon the cold cylinder walls during starting or cold running.

The corrosive products settle in the bottoms of the valleys forming the roughness, being held there to a great extent by capillary action. The corrosive agent now begins to undermine the hills, weakening them, so that they ultimately fall away. The corrosion spreads out into directions forming pointed hills, the angle of which seems to be constant for any particular material and relate to the crystal shape.

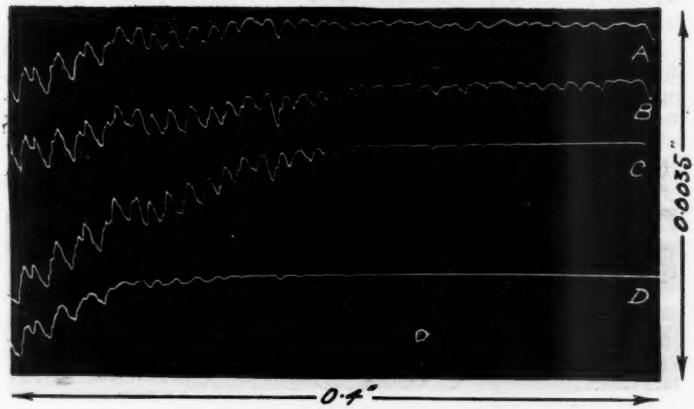

Fig. 14.

Surface of part of an engine cylinder including a local depression : (A) After motoring for fifty hours on plain oil. (B) After running twenty hours with plain oil and petrol. (C) After running twenty hours with plain oil and graphited upper cylinder lubricant in the petrol. (D) After 100 hours similar running.

The corrosive material can now concentrate in the valleys formed by the breaking way of the hills to cause further corrosion. This action is progressive, and as the depth of material removed at each stage depends upon the pitch of the hills formed by corrosion and this in turn depends upon the pitch of the hills of the original

roughness it is important from the point of view of corrosion to reduce the pitch of the hills. Fine-boring produces hills the smallest in pitch as compared with depth. The pitch should not be reduced to such an extent that the cells in the surface are so acute as to cause greater concentration of the corrosive products.

If the pores and bottoms of the valleys of the roughnesses can be filled or sealed with oil and colloidal graphite during the finishing process, the corrosive products have not the same opportunity of concentrating there and so causing corrosion, particularly as colloidal graphite acts as an inhibiter to restrain corrosion, and graphoid surfaces themselves are resistive of corrosion, as was proved by the way in which a shaft, previously run with a colloidal graphited oil, resisted corrosion from dirty oil, whereas a shaft run with plain oil did not.

The introduction of the lubricant colloidal graphite into the coolant prevents the formation of valleys with very sharp bottoms and so reduces the concentration effect of corrosive products.

Fig. 14 is a good illustration of the investigations that are possible by recording surface roughness. The four records are taken over a spot in a cylinder wall where there was a local depression. *A* was taken after the engine had been motored for fifty hours with plain oil and shows that the surface roughness that receives pressure from the rings is reducing, whereas that in the local depression is not.

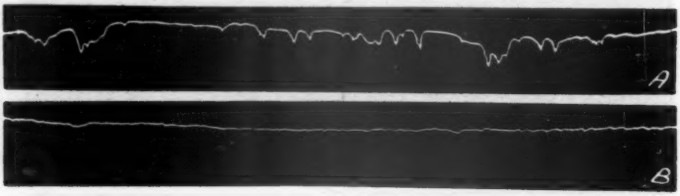

Fig. 15.

(A) Fatigue on a ball bearing race running on plain oil. (B) The surface of a ball bearing race run under similar conditions with an oil containing colloidal graphite.

B was taken after the engine has been run for twenty hours with a plain oil and fuel from which it will be seen that the bottoms of the roughnesses are being deepened by corrosion.

C taken after the engine had been re-assembled and run for twenty hours with a petrol containing a colloidal graphited upper cylinder lubricant shows how corrosion has practically ceased to deepen the roughness.

D is after one hundred hours similar running and still shows the absence of corrosion, though, of course, in both *C* and *D* the surface that receives pressure is gradually wearing away.

When tolerances are being fixed the finish desired should be specified on the working drawings. In addition the practice should be adopted of specifying that lubricant materials such as oil and colloidal graphite be added to the coolant used during the finishing of the bearing

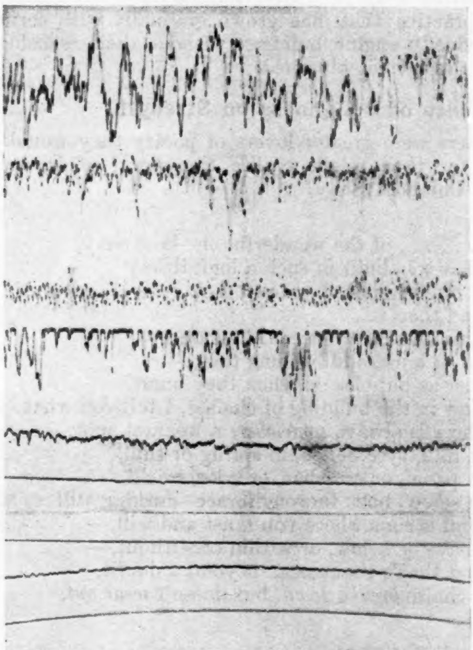

Fig. 16.

University of Michigan Profilograms of: Kwikway bored finish. Van Norman bored finish. Fine-bored finish. Kwikway boring polished. Burnished honed surface. Micromatic mirror finish (service tool). Johannson Gauge Block. Optical Flat. Ground aircraft cylinder finish. Mirror finished aircraft cylinder. Worn cast iron cylinder after 25,000 miles running. Carbon scratches after 40,000 miles running.

surfaces, for the purpose of imparting lubricity as described. Care should of course be taken that the coolants are suitable for the addition of such materials. Oil and colloidal graphite can be added to mineral oils, as sometimes used for coolants during cutting, to paraffin for use during honing or grinding, and colloidal graphite and water can be used for certain types of grinding.

The smearing of graphited oil on the surface during assembly prevents seizure while they are attaining the desired finish. This is, indeed, a practice that has grown gradually with certain manufacturers, chiefly engine builders, without their realising the real reason for the benefit obtained.

The Influence of Roughness on Strength.

If engineers were greater lovers of poetry they would be better engineers, for they might realise the moral of Oliver Wendell Holmes' "One-hoss Shay."

> . . . . of the wonderful one-hoss shay,
> That was built in such a logical way
> It ran a hundred years to a day
> And then . . . .
> How it went to pieces all at once,—
> All at once, and nothing first,—
> Just as bubbles do when they burst.
> Now in the building of chaises, I tell you what,
> There is always *somewhere* a weakest spot,—
> In hub, tyre, felloe, in spring or thill,
> In panel, or crossbar, or floor, or sill,
> In screw, bolt, thoroughbrace—lurking still
> Find it somewhere you must and will,—
> Above or below, or within or without,—
> And that's the reason, beyond a doubt,
> A chaise *breaks down*, but doesn't *wear out.*

As with one-hoss shays so with machines. If they had no weak point they would last until they burst like bubbles. Poor reconditioners !

A shaft that is equally strong throughout cannot twist apart under torsion or break under deflection. It is only because such a condition cannot be achieved that parts do break.

Sharp corners, as is well known, weaken parts considerably, by causing a concentration of stress at the corner. Similarly do scratches, whether they be occasional, or frequent as they are in a rough surface.

If parts subject to stress are free from stratches they are stronger, because stress concentration is less.

In certain classes of machinery it is cheaper to use a little more material to increase strength than to obtain greater strength by a better finish, but in other types, such as aeroplanes, where weight must be a minimum, it pays to obtain greater strength by giving a better finish.

Fig. 4, 5, and 7 appear by courtesy of the North of England Institute of Mining and Mechanical Engineers.

Discussion, Coventry Section.

MR. H. E. WEATHERLEY : It is indeed a surprise to be asked to open this discussion. I am afraid Mr. Shaw has got me rather confused with his graphs, so that I find difficulty in sorting it all out. But I congratulate Mr. Shaw on the thoroughness of his paper, and I should like to know whether those graphs are all in relation, i.e., in proportion. (MR. SHAW : Yes, in the original records the heights of the roughnesses are magnified 2,000 times and the horizontal distances 32 times). Have you tried Episcopical methods of checking surfaces ? To me they seem much easier, quicker, and more practical from the shop point of view ; that is, if a parallel beam with Episcopical attachment is used, with a fixed magnification you are able, provided that your projection is accurate, to measure the width on your graph quite easily.

MR. SHAW : Is that method anything like the Zeiss ? These light methods are quite good, and quicker than the others for comparatively rough surfaces, but when you are getting down to what the Americans call " millionths," the difficulty is that you cannot get a beam of light a millionth of an inch thick—so you miss roughness under 2 or 3 millionths.

MR. WEATHERLEY : I agree that is true, but for practical purposes —which is all that is required in the shop—a magnification of 100 is quite ample.

MR. SHAW : The roughness of the true mirror finish is about 15 millionths of an inch ; mirror finishing is a practical method of producing surfaces. You can get slight variations in this finish which for certain purposes it is necessary to detect. With your light method I don't think you can detect the slight variations between, say, 30 and 60 millionths. The contorograph can, with ease, on very smooth surfaces, detect roughnesses within an accuracy of two millionths. On rougher surfaces the error is slightly greater. Episcopical or light methods are good in the workshop for comparatively rough surfaces.

MR. CURZONS : What exactly is the size of the needle used for these serrations ? What is it made of, and exactly what happens when the needle traverses over soft surfaces as, for instance, cast iron ? I have heard that a particular firm had difficulty with the needle causing the material to push over, and instead of the needle falling into the valleys, it pushed the metal over and blocked them up.

MR. SHAW : With a soft material such as bored white metal, after 20 tests made over exactly the same spot you can detect no

difference between the first and the last record. The tracer point is very lightly applied. A gramophone needle has not a definitely sharp point, but a cone slightly rounded. To get a sharper point the cone is ground or lapped to a practically sharp point. Magnified 1,000 times the end of the point is about $^1/_{16}$ in. across. You might say that even this will not go into recesses smaller than itself. The records obtained and shown have to be stretched out to bring them to the same scale in both directions and consequently the needle enters all but the minutest of the undulations—those less than one-millionth or so of an inch in depth. The needle point really sets the limit to the accuracy.

Mr. Cole: A few weeks ago I was pondering over what had happened during the last few years in connection with honing in the automobile industry. In the early days we used to do boring—rough and finish; then we turned over to honing, and learned its good and bad points; now I think the latest practice is fine-boring. I would like to know what is Mr. Shaw's opinion on the matter from a service point of view and from an automobile point of view.

Mr. Shaw: Fine-boring gives you a parallel and cylindrical bore but a comparatively rough surface, which soon wears down, rapidly increasing the clearance. Some automobile manufacturers in this country who were honing started fine-boring and found a certain gain because they got cylindrical bores; but some of them are not now happy about fine-boring. At this moment various research departments in the automobile industry are investigating this matter of finish. The remarkable thing is that the originator of the modern fine-boring process, Max Krause, to-day is saying "fine-bore and then hone." Originally, makers of fine-boring machines said "fine-boring gives a good finish," but they have learned by experience that the fine-bored surface is not just what they want. If you study machines for fine-boring—particularly German machines—you find that provision is made for mounting a honing head for use after the fine-boring.

Mr. Hey (Chairman): I have thoroughly enjoyed the lecture myself, but I cannot see where all these things are going to benefit us a great deal. Yet as a whole it confirms my experience of "Oildag." I think I mentioned some meetings ago, in the case of pistons, after running them for six months, we found the graphite had penetrated ⅛ in. into the material, although this was a very fine-grained iron. Taking a practical outlook on the boring of cylinders and the fitting of pistons I don't know why we squabble about one millionth of an inch. I agree about honing, and it is my experience that if you get it started right you have very little trouble afterwards.

Mr. Potts: My mind was working along the same lines as Mr. Hey's. The height of the hills on the records is half-a-thousandth

of an inch, and from the slide showing the cylinder wall I assume that that pitch of those crevices was ten thousandths. That being so, I wondered whether we should not finish with the mechanics of removing metal and study the science of the metal crystals themselves. Some of the elements of the material would probably be harder than others and stand above the rest of the surface produced with the cutting tools.

MR. SHAW: When you get down to these very fine finishes you must use close-grained material; but there is also this point: by honing it is possible to get a finish which is smoother than the structure of the material would seem to allow—by pressing the hard crystals into the softer matrix, or body.

This problem of initial wear and as to whether, when the clearance is $^1/_{10}$ in. (to exaggerate), it is necessary to bother about millionths. Yes, it is. If you get a rough surface and it wears, what is happening to the material? It gets into the oil and circulates with it. A filter might not remove it all, or at least, not the finest particles. These would still circulate with the oil and cause further wear, so that the rougher a surface is, the greater will be the influence of the loosened metal on wear.

Defining initial wear as the wear during the period when metal is being released at a rate of more than $^1/_{1000}$ in. per thousand running hours, tests showed that the initial wear on a ground surface running under a load of 50 lb. per sq. in. at 100 ft. a minute was four times the depth of the surface roughness, whereas that with a fine-bored surface under similar loads and speeds was nine times the depth. So, if the ground surface had a roughness of 0.00011 in., the wear will be 0.00044 in., whereas if the roughness of a fine-bored surface were 0.0003 in. the initial wear would be 0.0027 in. From this you will see that the rougher the surface, the more often is this rougher surface worn away. The wear does not vary directly as the roughness, but as some power of it.

You might say: "If the roughness is three-quarters of a thousandth how can you produce shafts to an accuracy of less than that?" When you consider that the peaks of the roughness are squashed up together, and the micrometer will probably make contact over $\frac{1}{8}$ in., you have a quarter of 500—say, 60—peaks to measure over. The explanation is that you are measuring over all the peaks, and the valleys between do not affect the measuring.

Discussion, Edinburgh Section.

Mr. Bennet (Section President): We have listened to an interesting lecture, and it is certainly news to me, and possibly to others here, that surface roughness can be measured to a millionth part of an inch. I am interested at the moment in a pair of steel rolls in a rolling mill, the rolls being about 12 in. diameter by 20 in. long. I should like to ask the lecturer if he has any knowledge of tests for surface roughness such as he has shown us being made on mill rolls.

Mr. Shaw: So far as I know, the users of rolls, the steel rolling mills, are not employing the methods I have described for testing the surface roughness, but the roll grinding machine makers are interested and have had tests of finish made in their investigations on mirror finish on rolls.

Mr. Peet: We have this evening seen many records of measurements by this instrument. What would be the effect of measuring a broached hole by this method as against the motor car cylinder as shown on the screen? Has the lecturer any experience of this sort of thing; and also can he tell us what difference a graph would show between an aircraft air-cooled cylinder and a motor water-cooled engine, when colloidal graphite is used?

Mr. Shaw: The degree of roughness of a broached surface depends upon the conditions under which the broaching is carried out, upon the coolants used, and upon the condition of the broach. A good broached surface is about 50% rougher than a normal rough-honed surface. Incidentally colloidal graphite used as a lubricant during broaching will keep the broach in better condition and give a smoother surface. Ordinarily the finish by any process on an air-cooled aircraft cylinder will be better than that by the same process on a car cylinder block, because the metal is usually denser. On the other hand, a thin aircraft liner will take a more even finish than a finned barrel, if the finning causes a variation in density. Fine-boring on a finned barrel leaves a slightly ribbed surface that follows the contour of the finning unless the process is carried out with great care. A hone bridges the fins, whereas a tool does not. The effect of running is different on an air-cooled cylinder than on a water-cooled cylinder, because of the difference in the cooling; but even in aircraft work colloidal graphite has proved equally beneficial.

Mr. Lee: With reference to the slide showing wear on a car engine cylinder after twenty hours, fifty hours, and one hundred

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hours running, was not the linear speed of the piston a factor in causing wear? This must have varied enormously in the tests.

MR. SHAW: The linear speed would have influenced the wear, and for this reason in the tests referred to the engine was run under controlled conditions of heat, speed, and so on. The engine was actually run on the bench and not on the road.

MR. CAMPBELL: With reference to the various types of surface-measuring instruments shown, can Mr. Shaw foresee the possibility of these instruments leaving the laboratory and coming into practical use? In other words, would it be possible in the future to have the machine operative handling this instrument? Just as at present he may use a clock-gauge to determine the proper setting of the job, will he likewise have an instrument for measuring the surface finish?

MR. SHAW: I confidently believe that an instrument of the contorograph type could find use in the works as an ordinary testing instrument. Firstly, you should, however, find by its use what surfaces you required for different purposes, and then standardise and specify the procedure that will give the desired finish. The contorograph should then be used for checking periodically to find out whether the finish is being maintained. The instrument can, as mentioned in the lecture, be used quite conveniently by a person of average intelligence under works conditions.

MR. RUTHERFORD: I note that the bearing for the swinging pillar in Mr. Shaw's machine is a coned point. Will he please tell me what form of bearing he uses to steady the pillar since it cannot stand on one point? And, if it rotates within a sleeve, would not the roughness of the surface of the bearing in the sleeve affect the reading?

MR. SHAW: The vertical pillar rests in a long, very close-fitting bearing, and because the pillar does not make a complete turn, but only about a sixth of a turn, it rests all the time against one side of this bearing, and so no rise and fall of the needle takes place through inaccuracy in it or its bearing.

MR. CAMPBELL: With reference again to the practical side of Mr. Shaw's instrument as apart from research work, can it assist the engineer to-day, say in the case of a fuel pump, demanding a high finish, into which the spindle has been lapped and then undergone a paraffin test, to arrive at any further conclusions as to the finish required?

MR. SHAW: I believe that it can help the manufacturer of fuel pumps to arrive at a satisfactory finish for the parts; indeed, I have recently tested both bores and plungers of fuel pumps.

MR. PEET: Isn't there a possibility that the machine illustrated can be used with good effect as a "crack detector" in measuring

the minute surface cracks which are sometimes encountered in surface grinding ?

MR. SHAW : While my instrument would detect fine cracks due to surface grinding, as the instrument only covers at one test about ¼ in., an ordinary magnetic crack-detector would be quicker for this work. Once a crack had been located, the contorograph could be employed for telling something about its depth.

MR. RUTHERFORD : When your instrument is being used, is anything taken into account for the stress of the various kinds of material under measurement, such as in clamping the work in a three-jaw chuck ? Is any allowance made for the material springing ?

MR. SHAW : Large work is usually supported without clamping on the table of the instrument, while small work is mounted on plasticene so that it is not distorted.

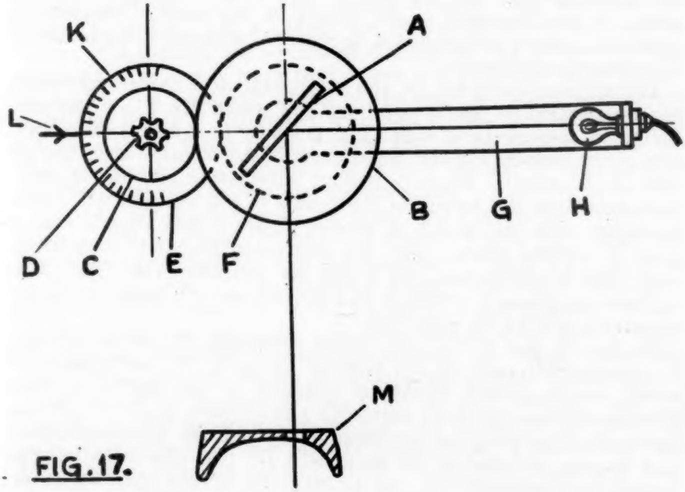

FIG. 17.

Discussion, Glasgow Section.

DR. JAMES WEIR FRENCH, D.SC.: On an occasion like this I should say that, although I am intensely interested in production, I can hardly claim the distinction of being a production engineer. I would congratulate Mr. Shaw on the presentation of a paper which is really half a dozen papers in one. It is an excellent instance of the compression of an enormous amount of material into the short space of an hour. I would congratulate him also on the instrument which he has produced. At first I could not see how the apparatus could do what was claimed, but I think he has demonstrated its usefulness by the slides and the repeat results displayed. Mr. Shaw has not only scratched the surface; he has penetrated very deeply into the subject. It must have meant an enormous amount of concentration and reading and individual thought. Personally I have been much interested in the subject and my mind at first was full of doubt. It is twenty years since I had practically to face the same problem, but in connection with glass. It was necessary to get data as to the rates of abrasion in relation to speeds and pressures, in order to get down to the question of emergency production.

The method I adopted for the measurement of the ground glass has no relation to the beatiful method which Mr. Shaw has put before us, because he is indicating, not only the general characteristic of the surface, but also the contour of the various scratches or cuts in the metal. He is providing information of vital importance regarding the nature of these cuts in the metal. All I was concerned with was to get an average figure so that I could take a piece of ground glass, make my measurements and, some time later, take it off the shelf and repeat my measurements. The piece of glass was put on a turntable and the filament of a lamp examined by reflection from the specimen.

In Fig. 17, *A* is the specimen upon a turntable *B*, driven through 2 : 1 gears by means of the head *D*. A lamp *H*, the filament of which can be clearly viewed, is mounted on the end of an arm *G* which rotates about the turntable axis at twice the speed of the turntable *B* carrying the specimen *A*, through the intermediary of 1 : 1 gearing operated by the same head *D*. The observer's head is located by a faceplate *M*. The arrangement is such that, whatever the position of the lamp *H* with reference to the specimen *A*, no change in the position of the head of the observer is required. Suppose, for instance, the lamp is turned in an anti-clockwise

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direction through 90°, the specimen will be rotated through 45°; therefore the beam of light will be at zero inclination to the specimen and the filament will appear normal. As the lamp is swung clockwise, the quality of the reflection will be determined by the decreased amount of the foreshortening of the surface irregularities, and the quality of the surface will become progressively poorer. At one particular point the well-defined white image of the lamp will comparatively suddenly turn red, owing to the scattering of the shorter wave-lengths. This change in colour affords a remarkably accurate characteristic figure for the roughness of the particular specimen and it is a figure that can be repeated with an accuracy of least one-half of 1% after the lapse of considerable time, provided that the surface is cleaned in the usual manner.

In the case of metals a characteristic figure sufficiently good for most practical purposes can also be obtained. The appearance, however, is rather different. The image of the filament now appears at nearly scraping incidence, has at its centre a clear, well-defined, white image of the filament. As the lamp is turned clockwise, the white image changes colour, becoming more blue and, thereafter, before reaching red, it breaks up quite rapidly and becomes diffused in the spectrum. The characteristic number can, therefore, be either the change from white to blue, or the diffusion point may be taken. The surfaces can be cleaned in the usual way before repeating the tests, which may have been taken a considerable time before. In the case of glass, the length of the scale *K*, which is mounted upon the wheel *E* associated with the handle *D* and read with reference to the index *L*, may cover 180°. The scale range in the case of metals of comparatively coarse surface is considerably less, but is ample for practical requirements.

I would ask one favour of Mr. Shaw, and that is, not to add this weapon to those already in the hands of the devisers of specifications. There is ample scope for it in the laboratory, where it can be most usefully employed, for the subject of roughness is full of opportunities for valuable research. I was appealed to, not long ago, by one of the Universities with regard to the provision of suitable subjects for research. In future I shall refer them to Mr. Shaw, to whom I offer my personal thanks for his interesting lecture. (Applause).

Mr. Shaw: I thank Dr. French for his kind remarks, and will take the earliest opportunity of looking into the matter he mentioned as another method of checking my own results. I cannot say that I quite agree with not handing out the method to people who draw up specifications, because the production engineer has often to decide what finish to give and is often in a quandary as to what will be accepted and so, to be on the safe side, spends weary hours in getting a beautiful finish when a normal finish would do. So, if the people drawing up specifications would use common sense, they

would make it a means for getting on better terms with the production engineer.

MR. J. McFARLANE, B.Sc.: I think the author of the address is certainly to be congratulated upon his choice of a subject which offers such scope and on which the stock of general information is somewhat scarce, and also upon his investigations and the result of his invention of the contorograph. Whilst appreciating all that has been done on these super-inspection-room lines, I cannot quite agree that you can bridge the whole gap between such investigatory centres and the man on the job. I think it is a matter that has been otherwise neglected. It has been rather a case in which Mohammed and the mountain are more or less mutually unapproachable. The future, from the practical point of view, lies in the use of a more portable, more applicable and more readable device. Again, in the system of specifying surface finishes as the result of an attrition test of parts of the surface, laboratory research is leading rather in a direction opposite to practical application. In many instances such a test would ruin the part involved; perhaps the intrinsic value of the work described would lie in causing people to cudgel their brains for a solution which is non-destructible whilst still conforming closely with the result obtained by Mr. Shaw.

Referring to the relative action of plain and colloidal-graphited oil, could Mr. Shaw adduce any reason for a plastic deformation by the use of the colloidal elements? It is an interesting point and it may possibly be that the character of the metals has great influence on the matter. Also, might it not be that the colloidal-graphited oil has more body in it than the plain oil and thus creates a swaging action between the two rough surfaces, which are therefore deformed rather than worn away? Certainly, with glass, there is definite plastic deformation of the surfaces, whereby the hills flow into the valleys, and a very high standard of finish can therfore be obtained.

MR. SHAW: I cannot agree that the instrument is not of practical value. I donot suggest that you give the instrument tothe workman, but I do suggest that first you use it to find how to produce the best finish by different methods, and decide which is the best; that you process your work so as to obtain the finish desired, and then periodically take samples of the finishes produced and see if they meet the specification. As to constructing a portable instrument, that can be done. It is quite possible to make an instrument no larger than this desk so that you could bring the work to it and put it on the slide of the instrument, or take your instrument bodily to the work. Personally, I have no use for such an instrument as my work is on the research side.

I must have misled you in talking about my specification system. I said: "cut away your surface, take a reading of the area that

will make contact, and then specify the surfaces." By that I did not mean actually "cut it," but that you should obtain a record with the instrument and then on the contorogram draw a straight line to touch the top peaks and a straight line so far down, measure up and find the percentage of area cut through by the second line and then you can give the specification for the surface. To test your work you take a contorogram from it and do your cutting or line drawing on the contorogram so that actually you do not destroy the work. As to why you get plastic deformation with one oil and abrasion with the other, I suppose that with a plain oil you tend at times to get metal-to-metal contact, when inevitably the tops will rub away, but with a graphited oil a graphoid surface follows the contour so that contact is between two highly lubricant graphoid surfaces that slide over one another freely, the graphite preventing abrasion. Continual pressure on the tops of the hills, although it may not cause wear by removal of metal, must spread the peaks into the valleys with naturally a polishing action. There is no great difference in the body of a graphited oil and a plain oil, but the different action is due to the better protection afforded to the bearing surfaces.

MR. DARBY: Might I ask Mr. Shaw by what means the needle with the fine point necessary for surface measurement was suspended? The reason I am asking is because my own experiences show that if the needle point is not very delicately poised when measuring soft work it will cut through the hills instead of riding up and down them. Also, if the surface of hard work is to be measured, there is great danger of the needle point being damaged and, of course, influencing the reading.

MR. SHAW: In the States, at Michigan University, they use a diamond point. Harrison uses a sapphire point. As for myself, I use the ordinary gramophone needle, but the point is lapped and projected for comparing with a drawing; the lapping is continued until the point as projected conforms within limits to the drawing; hence I know that the points, although not absolutely the finest obtainable, are uniform, and on fine surfaces of up to 30 millionths depth of roughness the error is less than half-a-millionth of an inch. This knowledge is obtained by deduction from working with different sizes of point, and noting the different results. On fine surfaces the error is less than on coarse. As to the needle cutting the surface: I have traversed a needle over a white metal surface twenty times and there being no perceptible difference between the first record and the last, I concluded that the scratching was inconsequential. On hard work fifteen tests can be taken with the same needle before detectable needle wear occurs.

MR. W. BUCHANAN: I would like to ask Mr. Shaw about the curve shown for fine boring. Some parts of it are vertical. How does

the needle accommodate itself to this working position? Does the same improvement accrue from the use of graphited oils when the surfaces in contact are of white metal and mild steel?

Mr. Shaw: The records are magnified more vertically than horizontally, so that what shows as an acute rise is merely an undulation. Undercut is a problem that worried me at first because if the surfaces are undercut, how can they be checked? The cutting tool is travelling across and producing grooves. The backward pressure from the tool forces the serrations backward and so produces a vertical and sometimes an undercut surface. Normally, the needle traverses across in the plane of the surface. But, if undercut is suspected, the surface would be inclined to the needle and so backward curves or undercuts would no longer be vertical to the path of the needle. I have not encountered a surface with a backward curve in both directions. The graphited oil is of benefit with white metal on steel.

Mr. W. P. Kirkwood: I should like a little more information as to the taking of records on small-diameter shafts, with particular reference to the compensation employed when records are not taken axially, the needle passing over a small radius. Has the author made any experiment to correlate his findings on surface roughness with the known qualities of certain materials to act as bearing metal? I have in mind particularly the fact that where you have a condition such as a steel shaft running in a steel bearing the depositing of a very fine film of copper on the shaft will make all the difference between success and failure. Is this in any way due to the copper deposits filling up the valleys and so causing more equal distribution of pressure?

Mr. Shaw: In the contorograph the needle traverses in a small arc, an arc of about 3½ in. radius, and the length actually tested is ¼ in. In a ¼ in. movement on a 3½ in. radius the actual curvature is slight, so when the traverse is along a shaft, even a small shaft, the rise and fall due to the curvature is very little. The movement over an arc, as at right angles to the axis of a shaft, will not affect the result, but if the drop is magnified 2,000 times you would need a film of a great depth to hold it; so, to enable such surfaces to be tested I adopted this method, which is simple: The cranked pillar rests on a screw. A lever attached to this screw can be moved to and fro by a cam, the screw so turning and lowering the pillar to allow the whole mirror and lever assembly to follow the curvature of the work, without affecting the record. By that means the curvature of the work is negatived and, if necessary, the method can be checked in this way by testing a piece of known curvature. I do not think the problem of different metals working in contact is affected by the surface roughness so much as by the nature of the metals themselves. The better working is probably due to the

affinity of the metals for one another, or to the lack of it. There may be some molecular influence which causes them to stick more. As to the thin coating of copper, that leads to the subject of colloidal zinc-oxide in oils.

MR. W. PATE: I would like to add my tribute to the excellence of the paper to which we have listened. There were two points which appealed to me. First, the practical justification of the instrument. It is certainly needed, if only to act as a referee in the discussions that so frequently take place as to the grade of surface being produced, and I think the contribution Mr. Shaw has made in this research is valuable indeed. My other remark is in lighter vein: Mr. Shaw's handling of the subject of lubrication has been done with great consideration for the peace of mind of the production engineer, because it seems to me that the first part of the paper intended to show how difficult it is to produce a perfect surface, and the second to show you how easily that may be done by adding graphite to the oil. I incline to the graphite way.

MR. T. WHITE (Section President): In closing the discussion I might say that I was interested in the point raised by Dr. French regarding the specification laid down by Mr. Shaw, and the difficulties which might arise in connection with Government inspectors because, in laying down his specification, Mr. Shaw does not mention any danger line. If we are to be tied down to still finer finishes I would ask: "Where is the point beyond which it is dangerous to go?" because it is conceivable that, if too fine a finish is specified, we may get molecular adhesion such as has occurred with Johansson slip gauges.

One other discussion which will be dispelled by this instrument is as to whether scraping is superior to grinding or vice versa for the finishing of surfaces which must operate in sliding contact with each other. This instrument will decide, without any lengthy discussion, which is the better.

MR. SHAW: As to the danger line, that is a problem, but I do not think that the financial powers that be in the works will allow the production engineer to get anywhere near it. Whether a scraped surface or a ground surface is the better from the point of view of roughness is not a question so simple as it looks. I took all these records and then went a little further and said, "But is this record I obtain a complete description of the surface? Am I really detecting the true roughness, or something false? Is it apparent roughness I am getting and not true roughness?" And so there is a more complicated aspect to the problem, and, moreover, we have to investigate the influence of the weight put on the stylus or tracer point. We start first of all with six finishes on six cylinder bores produced by a well-known automobile firm, and test them, and as far as I can see we find they cannot go wrong whichever finish they

use. There are six, and all alike, but I knew beforehand that though No. 1 was very like No. 6, the initial wear was different. This was not due to surface roughness altogether. Then the question arose as to whether the surface was a true or a false one, and I struck the idea of putting more weight on the needle. This caused a slight difference. I increased the weight again, and again, and ultimately got six different records. When the pressure was 20 grammes the records from the surfaces varied considerably from the original surfaces, for four surfaces, the last two remaining unchanged. So, four of the surfaces were false or loose in structure. But we must carry on further to find the real truth.

Discussion, Eastern Counties Section.

Mr. Rackham : It has occurred to me in listening to this most interesting lecture, a lecture which is so out of the ordinary that it is more particularly interesting, whether Mr. Shaw considers it possible to lay down some specification for measuring surface roughnesses—for instance, a British Standard Specification that might be adopted for that purpose. I remember that the firm with which I am connected required to order out a number of spindles with a polished finish. All we could really say was we wanted "polished finish." A very ambiguous term. The lecturer showed some Zeiss photographs of surface finishes. I am wondering to how many magnifications they were taken. Another thing that occurred to me was whether Mr. Shaw, during his lengthy investigations, has come across a particular metal or group of metals on which it is easier to obtain a highly polished finish. The methods explained for measuring surface finish seemed rather lengthy, and I am wondering whether there is a ready method from which one could judge the finish of an article without destroying it or even getting specimens from it.

Mr. Shaw : I think it is possible to set a standard ; in one's own works it is easy. You find the actual roughness you get, then draw up a specification for each particular type of finish. You can then say : "For this particular job we want a certain finish, and for this, another," and so on, specifying and charting the methods, materials, tools, and coolants necessary to get the finish. You simply specify the finish and the man in the shop consults the chart.

You may standardise your own works procedure, but when you buy outside, it is rather a different matter. You have to educate your suppliers to the procedure, to tell them how you could get the finish in your own works. I think it is possible to lay down a uniform specification for finish for your spindles, and insist upon your suppliers working to that specification.

The ideal material for finish is glass. With a softer material, such as aluminium, you get a very good finish by a definite process. Then come bronzes and brasses ; then steels and lastly cast-iron. Cast iron must be close-grained to present a good finish.

The magnification of the Zeiss photographs was 80 in both directions. The Zeiss is a good and quick method for comparatively rough surfaces. For finer surfaces the record is not clear enough.

The procedure indicated in the lecture may look lengthy, but

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actually I could turn out a finished contorogram in ten minutes, provided that all the materials were at hand. In production work you should be able to obtain a contorogram in five minutes. I am trying to do away with the photographic record and to get a beam of light to control photo-cells in such a way as to enable readings to be obtained by the movement of a pen over paper. I think that the present instrument is good for workshop use.

MR. COPPING: I would like Mr. Shaw to tell us what is the effect of the stylus on the material being tested, and also the effect of the material on the stylus. It appears that if you are trying to trace the finish with this instrument, with a material such as aluminium you would probably mark or destroy part of the surface of the soft material. On the other hand, if you were tracing a hard material such as in a ball-race, would there not be a blunting of the stylus and danger of not getting good readings?

MR. SHAW: Actually, I have tested a piece of babbitt and in making 20 records over it I got not positive differences between the first and the last—a definite proof that the stylus does not scratch the material. There is no consequential wear on the needle because the pressure is slight. On my instrument it is never more than 10 grains. The same point was raised by the N.P.L., who said it would be impossible to use this system with any degree of accuracy because the stylus would wear the surface. I have proved that this is not so. The N.P.L. recently evolved an instrument in which the edge of a razor blade is passed across in steps—a tediously lengthy process.

MR. MURDOCK: Mr. Shaw has knocked some of our old theories on the head. In the old steam-engines it was more or less recognised that a few grooves in the cylinder bore would hold the oil and so better the lubrication. Has the addition of colloidal graphite any effect on the hardness of the walls? Mr. Shaw mentioned the filtration of oil in engines. In the engines of certain tractors in the Soudan we found that filtration of oil to the crankcase got over the troubles experienced.

MR. SHAW: Modern research shows that with a film of oil one millionth of an inch thick the hydrodynamic laws of full-film lubrication are fulfilled. Colloidal graphite enabled the surface to take on a glass-hard finish, because the running is under better conditions. It is important to keep the oil clean and, of course, necessary to filter the air passing into the engine.

MR. FARRAR: We have been discussing colloidal graphite recently and the suggestion was put forward that we should smear certain parts with it for assembly. Against that it was suggested that when we filled up these parts with grease we should drive away the colloidal graphite and waste it. Would the colliodal graphite stick

to the surfaces to such an extent that it would not be washed away by the grease ?

Mr. Shaw : There is danger that you may remove some of it, but a film of it adheres. Actually, attempts made by the Imperial College of Science to clean a surface with solvent and so remove the graphite were unsuccessful. Professor Finch describes a similar attempt. He smeared a surface with colloidal graphite and cleaned it ; but electro-diffraction examination showed that the graphite was still there.

Mr. Murdock : Colloidal graphite has to be used with a little discrimination ?

Mr. Shaw : Yes, that is true. It is expensive, and it would not pay to add it *ad lib*.

Mr. Jewson : We have heard about lubricating oil and graphite. Can you tell us how a cutting lubricant actually operates ? If you have a good cutting compound or a poor one you get a corresponding result. Does the lubricant get to the point of the tool ?

Mr. Shaw : Some coolants are used as lubricants and should lubricate the cutting edge ; but some do not lubricate at all : they are purely coolants. The difficulty is to get the coolant to the cutting edge. You can only do so, so far as I can see, by forcing it with a good pressure, so that it actually reaches the edge. You must also maintain a good flow. To get good finishes, you should use high speeds and fine feeds and keep down vibration. There is another point : If a tool gets a large built-up edge, the very fine particles of the edge break away, roughening it and robbing the tool of its keenness. In the States, at Michigan University, experiments showed that colloidal graphite had to be introduced to avoid that large built-up edge. The average coolant does not obviate the trouble, and you must mix with the coolant a preparation such as colloidal graphite.

Mr. Carrick : Can you give us an idea of the size of the crystals of cast-iron cylinders ? Are they very obvious on the record, and to what extent do they affect the up-and-down movement on your screen ?

Mr. Shaw : In cast iron, the amplitude due to the crystallisation is something like 10 millionths of an inch. A crystalline structure, to certain extent, prevents smooth finish. Apart from the roughness you seem to get a mottled appearance with some finishes. On other cast-iron surfaces you can see a mottling due to graphitic inclusions.

Discussion, Birmingham Section.

MR. E. P. EDWARDS (Section President): After listening to Mr. Shaw's excellent paper, and his final wind-up with a quotation from Oliver Wendell Holmes, I rather think we ought to regard him as something of a Sherlock Holmes in regard to surface roughness. I am sure Mr. Shaw has put forward contentious matter. I am rather wondering why, as I do not use colloidal graphite in my car, the damn thing runs at all, particularly after seeing those Himalayas, although I derived some comfort from the fact that they are not really Himalayas, but are stretched out until they are more like the Clent Hills. One thing that struck me as being very interesting is the effect of colloidal graphite on corrosion, and this is a point quite new to me. I don't know whether any of the members present are aware of this, but it seems to me very interesting. May I ask Mr. Shaw how he arrived at those deductions, which he very carefully told us were deductions and not records, where he showed what might be described as turned-over tops and apparent undercutting from burnishing?

MR. SHAW: To obtain the result illustrated in connection with burnishing, two specimens were taken of apparently similar finish; that is, where the original ground or etched surface was similar in roughness, one produced by straight grinding, and the other by burnishing. These two specimens were carefully submerged, after cleaning with oil solvent, in a corrosive medium. They were then washed thoroughly to remove all traces of corrosive matter and surface records made, when they were protected by a neutral grease and set aside for a considerable time. Later they were cleaned with oil solvent, inverted, and rapped, both under similar conditions, and a further record made of the surfaces.

It was found that minute pieces came off the burnished surface, whereas the other surface retained its normal contour. From that I concluded that the corrosive matter had got beneath the surface and could not be removed by washing. It could only have been trapped there by a roughness of the type shown on my illustration of a burnished surface, because from an open roughness it would wash out. From the burnished formation it would not do so because of capillary action which would prevent the washing medium from removing the acid. Hence my conclusion that there must be porosity under the surface.

To get an idea of the shape of the burnished roughness I section the surface and view it under the microscope. Another way is to

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finish the surface carefully with a smooth cast iron lap and then take a contorogram, so that a picture is obtained in which undercuts are not shown as such but as steep-sided valleys. After further lapping another contorogram is taken. Of course the needle cannot pass underneath, so actually it falls from the edge of a pit, hits the bottom, and climbs out again giving a steep-sided valley effect on the contorogram. From a combination of the records can be built up the shape of the undercut, for after each lapping some of the valleys instead of getting narrower at the top, as they would if they were true valleys, get wider, indicating definite undercuts.

A VISITOR: May I ask what is the effect of colloidal graphite on the hones; whether it would not have a clogging effect?

MR. SHAW: No. You get, of course, penetration of the structure of the stone by the colloidal graphite, but you do not get that loading which would cause clogging. As I mentioned, colloidal graphite has no strength in shear, so it would not build up on the abrasive grains. The essential feature in honing or in grinding is that immediately the grains dull the pressure becomes great enough to force them from their bond, and it is by this more or less continual falling away of worn grains of abrasive that honing stones remain sharp, so to speak. Also, colloidal graphite does not build up because there is a good circulation of paraffin. The colloidal graphite penetrates into the body of the stones.

MR. SILVER: Mr. Shaw, *inter alia*, has spoken of colloidal graphite, and its effect on motor car bearings. I should imagine that from the manufacturer's point of view it is an advantage to use oil containing colliodal graphite when running-in engines. If that is so, do the majority of manufacturers use oil containing colloidal graphite for this purpose? I believe that it is the practice of some commercial motor-car firms, when they are fitting the crankshaft to the journals, to clamp the journals dead tight and rotate the crankshaft until the white metal bearings become almost plastic. Afterwards they slack off the journals and set them to the correct clearance. What effect would that have on the surface, and what is your opinion of it?

MR. SHAW: Yes. Many concerns do actually use colloidal graphite when running-in their engines. There are probably more using it than is known, because certain manufacturers recommend certain oils, and I suppose that to some extent it would be rather embarrassing for them to say that they use colloidal graphite during manufacture. Many, too, use it during manufacture, both by smearing it on the parts and by adding it to the oil during the actual running-in. Whether they leave it in when the car goes out is another matter. They might actually use it during manufacture without putting it in the car when it goes out.

Under certain loads and speeds you can, during the burnishing of crankshafts, get very hot bearings, but provided lubrication is profuse, as it can be, the surface produced is run-in and glassy in appearance. It has been proved that the surface produced by running-in is far better for future running than that yielded by any machining process, but it is important to control the conditions so as to get that glassy surface, and not a roughened surface. If you get a partial pick-up during the burnishing, you are bound to get slight roughening, and anything you can do to prevent it will improve your ultimate surface. I certainly have recommended in the press that colloidal graphite be used during the process and stated that it will improve the running.

Mr. Boughton : Viewing a surface under the microscope, can you distinguish its structure as apart from what we term the "smarming" effect of it ? Very often, in polishing, what one tends to do is not so much to polish the surface of the material as to "smarm" it over, to spread out the hills. I take it that in polishing micro-specimens one really has to use an etching reagent to remove that effect, so that one can actually observe the grain structure underneath it. I think the lecturer dealt rather too quickly with fatigue cracking. One knows that perhaps the greatest cause of fatigue cracks in metals is due to the conditioning of the surface, and I think that we could, perhaps, usefully have some enlightenment on that, in the relation of surface finish to resistance to fatigue cracking. I should also like to know just how the lecturer prepared his needle points to get down to such fine limits as millionths of an inch.

Mr. Shaw : If you take contorogram of an etched surface (always remembering that you get a very definite saw tooth record) seemingly you get the shape of the grains or crystals—a fairly sharp shape ; and generally the pitching of the hills is less, and more regular than on a machined surface.

I presume that Mr. Boughton means by "smarming" a spreading of one constituent into another, say a soft matrix into the space between the hard grains. You do get that during the running, the soft grains spreading into the spaces between the hard grains. Some people claim that the good running properties of some materials is due to this disposition of hard grains in a soft matrix. Naturally, if you want the best finish, you can get that by, first of all, producing the surface in the customary manner, and then etching and polishing it. This gets rid of some of the constituents, hard or soft, depending upon the etching reagent, so that at the subsequent polishing you stand a better chance of getting a really good surface. During the preparation of metallurgical specimens, it is customary to etch them and then

polish them with various felts so as to get a really good surface ; then to give a final etching to remove the soft material that may have spread over.

The Michigan Profilograph employs a diamond which, it is claimed is more or less wearless, enabling the point to be used for a tremendous number of tests before it needs reconditioning. Personally, I use a gramophone needle. You probably know that a gramophone needle point is not sharp but rounded, so I lap it, by special apparatus to a sharp point. You might say that lapping or grinding will give you points of different dimensions so that if you test with a point of one size on one surface, and another size on another surface, you get different results though the surfaces might be alike. To overcome this difficulty, the needle is projected and its contour compared with a diagram having the limits marked on it. A needle not within these limits is either scrapped or re-lapped. Thus, while I may not be using actually the finest points obtainable, I am using points of uniform size and ensuring strictly comparative results.

MR. HIGINBOTHAM : A speaker has just raised an interesting point ; that is, the alteration to the surface of the metal. Some experiments recently carried out on the electron-diffraction examination of surfaces at the Imperial College of Science and Technology, have shown that run-in cylinders or liners have a different structure on the surface. In support of this statement I will read an extract from a paper on "Electron Diffraction of Surface Structure" by Professor Finch and some of his workers :—

> Recently we have examined the working surfaces of four aeroplane engine cylinder sleeves . . . Two of these sleeves were honed and ready for service ; the other two had been run-in, the one for forty hours, the other for 140 hours. After removal of the protective grease layer by washing with petrol-ether, the external and internal surfaces of the virgin sleeves both yielded patterns characteristic of a random crystal structure . . . The run-in surfaces, on the other hand, after degreasing gave the halo pattern typical of the Beilby layer. The thickness of this layer was such that several abrasions with No. 000 emery paper were necessary before the halos gave way to the normal well-defined ring pattern of the virgin sleeve surfaces.

They consider the deductions thus :—

> . . . it seems that the process of running-in an internal combustion engine consists in the formation on the working surfaces of an amorphous Beilby layer of considerable depth.

I understand that this effect can be obtained by rubbing together two pieces of metal for a certain length of time, and

that it is due in some measure to the flow of metal on the surface. Another point I should like to raise is on one of Mr. Shaw's pictures. The one in question is where the bottom of the hills were shown as attacked by corrosion. Whenever sliding had occurred, these hills were completely toppled over, leaving a series of small holes or grooves. I would like to ask Mr. Shaw if he has any evidence, by means of his contorograph, of the formation of what appear to be small grooves.

In another of his pictures he showed the surfaces of races of ball bearings as evidence of the alteration of the structure of the surface due, he says, to fatigue, where a plain oil was used, and in another where, with a colloidal graphited oil, he seemed to get a much better surface.

It has been stated by some people, in connection with the lubrication of ball bearings, "Do not use graphite." I would like to try to distinguish between graphite and colloidal graphite because there is a difference in their behaviour. In view of that statement, "Do not use graphite," it seems to me from Mr. Shaw's diagrams, that instead of saying "Do not use graphite," that to get a good surface on ball bearings and to resist the effect of fatigue, one should use an oil with colloidal graphite.

Tests have been carried out at the N.P.L., ball bearings being run for a certain time with an oil containing colloidal graphite, and no ill-effects at all were noticed, but in that particular test the effects that Mr. Shaw has mentioned were not looked for. I think Mr. Shaw has produced in the contorograph an instrument that should be of considerable assistance to production engineers and those engaged in producing surfaces of various kinds.

Mr. Shaw: This matter of the Beilby layer, or change of the surface from the crystalline to the amorphous structure by running-in is, of course, that formation of the glassy surface I referred to. It is a subject very much engaging the attention of our scientists at the moment. Highly refined electron-diffraction tests are being made with the object of studying the Beilby layer, and I notice that similar experiments are being made even in Japan, and when Japan begins to study a matter it assumes importance.

How do we obtain evidence of these undercuts or pockets? If a needle is travelling in a direction such that the surface presents undercuts in relation to the centre line of the needle I cannot make the needle go underneath, but what I can do is to tilt the surface until these undercut portions are no longer within the vertical line, and the needle then follows down the whole of the countour where undercutting is suspected. By experience, after carrying out many tests, one soon realises where to expect undercutting. The surface is tilted first in one direction and a record obtained, and then in the other direction, and the two records combined and from the com-

bination the final curve is derived. In the face-turning process I showed, you will remember that the one side was vertical. That is characteristic of any face-turning operation. The tool, apparently, in passing across the work forms one valley and pushes back the hill previously formed. If you have studied the diagrams and records obtained by Dr. Willy Kieswetter in his experiments you have noted that they show the same type of surface roughness from face-turning.

Probably the criticism on the use of graphite in ball bearings is due to people in the past having been rather more familiar with ordinary flake or powder graphite. You can get building-up on the balls and on the races if you use such graphite and with the very small clearances ball bearings have you are soon going to get sticking of the balls, particularly if there is plugging or loading or clogging round the ball in the cage, hampering rotation. Thus ball bearing manufacturers, to safeguard people against ordinary graphite, simply say "Do not use graphite in ball bearings," without considering that there is any other graphite than flake or powder.

Colloidal graphite cannot build up; that is to say, it can form indefinitely thin films, but it cannot increase the diameter of the ball, nor can it constrict the races. I think ball bearing manufacturers will in time realise that they should qualify their remarks and not say graphite generally, but powder or flake graphite. Of course motorists are using lubricating oil containing colloidal graphite.

MR. E. T. COOK: I should like to ask Mr. Shaw if he has any information as to the effect on static friction of ball races when colloidal graphite is used, referring more particularly to his last remark.

MR. SHAW: I have no actual figures on static friction, but I do know that, provided that you use oil of the same viscosity, and you add colloidal graphite you do get a slightly easier start. I should imagine that this is due to the quicker formation of the oil film. It is rather an interesting test to take a surface, smear half with colloidal graphite and leave the other half untouched and then carefully clean the surface. If you now drop oil on the surface it will spread more quickly over the graphited half than over the other, proving that spread is faster. It is possible that this quicker oil-spread helps in ball bearings. The graphited oil will attach itself to the balls more quickly after they have been stationary than plain oil. If the halt in retation is slight, then I do not know whether you get lower static friction than with plain oil. Probably you do, because tests of plain journals indicate that the static friction is lower under such conditions. If you continually stop and start ball bearings, you do get less wear with colloidal graphite, and if wear is caused by friction it follows that the static friction is lower.

MR. E. D. BALL: I would like to ask Mr. Shaw whether he has any comparative figures on corrosion in cylinders with different types of piston, that is, with an aluminium piston and cast iron piston—is the action corrosive? I think it has been proved that one would expect the electro-chemical effect to be very much greater between dissimilar materials in contact such as aluminium and cast iron.

MR. SHAW: Some wear is undoubtedly due to corrosion, and the wear is greater with an aluminium piston than with a cast iron one. This may be due to the dissimilar metals giving rise to electrolitic action, but can also be due to the more liberal disposition of free graphite in the cast iron, which spreads on the surfaces, and also to better adhesion of oil to similar metals, say two cast iron surfaces, than between a cast iron surface and a surface not cast iron. The better adhesion of oil will, of course, retard corrosion.

A VISITOR: I note that Mr. Shaw has confined his remarks on colloidal graphite to bearings and friction surfaces such as pistons and cylinder bores. I think he has fairly convinced me that the use of colloidal graphite would be an advantage, and it should have many other purposes besides that. I should like to know if he has any information on the use of colloidal graphite with press tools, not blanking out tools but drawing tools making deep pressings. It should be of advantage here.

MR. SHAW: As you know, certain of the lubricants used in deep drawing contain various powders, sulphur, and talc, for instance, introduced to cause the oil to cling better to the surface, because blanking wipes off the oil. When sulphur or talc is present the oil clings to the surface where it is wanted. Sulphur and talc are good high-pressure lubricants and withstand the pressures and sheering or sliding action of blanking. Powder or flake graphite is used in drawing, but, as far as I can gather, the graphite drys on the surfaces of the metal and is rather difficult to remove, particularly if it is used in paste form. Sulphur, being lighter in colour than graphite does not give rise to objection on account of colour on light-coloured pressings. Colloidal graphite does not dry on the surface. If added to the paste, it is removed by the oil and does not build up or flake off. It has been used in drawing, but is comparatively expensive, the quantity you get for the money you pay is, bulk for bulk, very little compared with that of other lubricants.

In drawing and blanking where a big surface must be lubricated a fair amount of lubricant is lost, so that economically for these operations it is not attractive; but for difficult press operations where you must have the best lubricant, and where the price of lubricant does not matter, then there is an advantage in using it, in an operation where the bulk of the lubricant is lost, no matter what are the benefits you get from it, you cannot use it economically

if it is a certain price, but on difficult operations, say on tubes whose length is great compared with their diameter, the tool wear is less and the drawing easier. Generally in such drawing the the surface areas are not great and so the economy factor does not enter.

A point in connection with Mr. Ball's remark on dissimilar metals. In a test being carried out it was noticed that in an engine slight pitting or signs of corrosion occured where the sparking plug enters the cylinder head, and chiefly on one side, where the fresh petrol vapour enters. As an experiment, nothing more, the sparking plug was chromium plated, when it was noticed that pitting no longer occurred. Whether the electrolitic action between the bronze of the plug and the cast iron of the cylinder was more severe than between the chromium and the cast iron, I do not know, but anyhow, the pitting had been arrested. Certainly an interesting experiment.

Mr. E. T. Cook : Shall I be out of order in addressing a question to our machine tool friends here to-night ? In view of what they have heard, will they recommend that the users of their machine tools lubricate them with colloidal graphite ? Are they convinced yet, and are they in a position now to make a statement ? It seems to me to be a matter of very great importance to machine tool users.

Mr. I. H. Wright : I am sure I voice the opinion of all when I propose a vote of thanks to Mr. Shaw for his most terrifying paper. I have been at it a long time, and remember how, when micrometers first came into use, we were much worried about the trouble that they were going to cause in the shop. Since then, other things have come along, bringing every time another complication that production people had to work through, and now Mr. Shaw comes along and he is going to magnify surfaces two thousand times ! It really is terrifying.

Relating to one of the early slides, Mr. Shaw said something about the wearing producing 30% surface, and getting down to a total surface. I believe it is now a fact that certain bearings are made, and have been proving very satisfactory, where one of the walls is definitely cylindrical, as cylindrical as one can make it, but the other wall can be lobed. It is claimed that for fairly high speeds it is better to provide a number of places where the oil can be taken in, rather than to aim at one oil entrance only. There should be some reason in that, if the pressure and speeds are suitable, but probably such bearings would not do for a wide range of speed. Mr. Shaw also discussed points and gave answers which, I think, are perhaps subject to a little further discussion, such as difference of metals.

Apart from electrolitic action, which of course can occur with difference of metals and occurs very mysteriously in some cases, is it possible that the difference of metals which we ordinarily use in bearings, a steel shaft in phosphor bronze bearings, for instance,

causes the contours of those two metals to differ in pitch and form, so that the oil film has a better chance of carrying the load, so that there is no kind of interlocking on the surfaces which might be very destructive ?

With regard to the use of colloidal graphite, here is an interesting case which I would like to add to Mr. Shaw's collection. We make quite a number of machines with hydraulic feeds, and in these machines are quite a number of piston valves, several pistons on one stem, hardened and ground. We make as good a job as we can of them and they run in a cast iron lining usually, but occasionally we had trouble from these valves, which were, of course, ground in a cylindrical grinder, not axially. We had trouble from these occasionally sticking. They had to be kept a very close fit, and our remedy for that was, in starting up the machines, to run them with colloidal graphite in the oil, and then they gave us no further trouble. We do not, I am sorry to say, particularly recommend our users to continue to use colloidal graphite. Propaganda has not gone so far, but certainly for the first few weeks colloidal graphite has got in its beneficial work and saved a lot of trouble.

With regard to colloidal graphite, and answering Mr. Cook, generally machine tool makers are, I think, favourably disposed towards it. They cannot recommend it because the user of the machine tool usually claim that he knows far more about lubrication than the machine tool maker does. And as colloidal graphite, we hear, costs a little more, we do not dare to suggest that it should be used. If, however, he cares to use it, the machine tool maker would say " By all means." I have apparently been criticising the paper, but I assure Mr. Shaw that I very much admire the consistent way in which he has built up his thesis, and envy him the interesting time he has had in building and using his contorograph.

Mr. Shaw : The lobed spindle is, of course, a very interesting application of a usually ill-effect being utilised beneficially. You get there the wedge formation often aimed at in certain types of bearings, such as rocking bearings. Mr. Wright's point on the difference in metals, whether besides difference in the metal themselves there is difference in the roughness, or pitch of the roughness and so on. The pitching has a big influence. As one writer put it—and this is perhaps against my own arguments—a perfectly smooth surface is absolutely useless as a bearing surface, because there are no recesses in which the globules of oil can roll, so that perhaps we have not yet attained the ideal. Obviously, if you get equal pitching in two parts rubbing together, you tend to get a locking effect, so you should aim at getting pitch differences. One method is to use dissimilar metals. Again, probably the action of one metal with hard particles evenly spaced in a soft matrix, will enable you to get surfaces which will bed perfectly together, but the roughnesses of which

will not bed properly. Difference in character is essential. It is a fact that a cylinder finished by a longitudinal motion has a surface which will run better initially than one in which the finishing marks cross the axis. For instance, longitudinal marks will give better running under reciprocating motion than will grinding or honing marks. A difficulty is that these longitudinal marks may cause scratches in the rings that will give a tendency to leakage passed the piston rings. There should be at least one pitch spirality in those marks so that they prevent scratches from forming in the rings.

Discussion, Western Section.

CAPTAIN BURGOINE: First of all, is the instrument Mr. Shaw described yet developed to any sort of practical condition, so that one might purchase it to use in a factory? If it is not a secret, what material is used for the stylus passing over the surface; what is the form of the stylus; how long does it wear; and what is the effect of drawing it over a soft material such as bronze? Does it not scratch, and is there no tendency to damage a really good surface? The paper seems to be really divided in two parts. One part deals with means of detecting, measuring, and recording surface roughness; the other with the advantages of colloidal graphite. These two subjects do not seem to be such as really should be embodied in a single paper. I should like to know whether the author has any experience of the use of colloidal graphite as a lubricant during the actual machining or finishing. I have heard that certain firms in America use it in small quantities during honing, with, it is claimed, good results.

MR. SHAW: With regard to the state of development of my instrument: so far I have only constructed one for my own use, but if anybody wanted one I could supply it. The conditions under which it is used are similar to those in a factory. Only a few feet away is running a 1 h.p. single-phase motor, causing vibration, but this does not affect the results at all; nor are they influenced by heavy passing traffic.

With regard to the stylus: in the States, at Michigan University, a diamond is used, which, it is claimed, won't wear. Harrison uses a sapphire for which he claims the same. I use an ordinary gramophone needle. As you know, a gramophone needle has a rounded point, so what I do is to lap the point and project the contour of every needle on to a diagram. If the contour does not closely correspond to the diagram the needle is scrapped or relapped. I use a very fine oilstone for this lapping. The projection occurs while the needle is in the chuck. So that little time is lost. I must have the finest point practicable, and all points must be uniform so that the results are always comparative. The pressure on the needle never exceeds 10 grains. I have actually passed a needle over babbitt metal 20 times, and there has not been any essential difference between the first reading and the last. Even on hard surfaces the needle can be used 15 or 20 times before it wears appreciably.

It is not clear, Captain Burgoine remarked, how the two subjects —measuring surface roughness and the influence of colloidal

graphite—can come into the same paper. Now if I had finished my lecture after dealing only with its measuring part, you would probably have said, "Where is the practical application of this?" My object has been to show how instruments can be used for research on running problems, to find out what happens to surfaces rubbing one another.

Have I met with the use of colloidal graphite during machining? I referred to that when I recommended the introduction of colloidal graphite as soon as possible in the production of surfaces. Actually there are people in this country who add colloidal graphite to the paraffin used in honing. In the States colloidal graphite has been effectively used during machining.

Mr. Daniels: Do any of the diagrams shown apply to bearing surfaces—to bearings "run-in" on their own shafts; that is, where a bearing is tightened on the shaft, and the shaft then rotated in it; and does this method give a satisfactory wearing surface?

Mr. Shaw: In the slide (Fig. 13) showing the effect of wear, three diagrams go to each set. The journals were 2 in. diameter and about one diameter long, the bearings complete ones. The load was on the top half, to which oil was fed through a single hole, though provision was made for it to pass completely round the bearing as the shaft rotated.

Mr. Daniels: Have you tried using split bearings and tightening them up as they are run in?

Mr. Shaw: Yes. The trouble is that if tightening is not done carefully and there is not a good supply of good oil there is some tendency to pick up if the halves are clamped tight to the shaft.

Mr. Aust: With regard to the instrument shown on the first slide, the speaker mentioned that the frequency response would have some definite effect on the results. What would be the average frequency the machine would be expected to record?

Mr. Shaw: I do not know the frequencies. A firm in this country use a variation of Harrison's instrument and they find that the results of the tests they make over here do not in any degree compare with those emanating from America. I was with the firm a short time ago and they believed this is due to faults in the system, to varying frequency response, and to the sound bearing a greater relation to the pitch than to the depth.

Mr. Whitehead: During a trip to the States I followed this subject up closely to find out if any firm was really doing anything with regard to it in a practical manner. I found out that nothing had been developed to a stage suitable for practical use. The nearest I found at Jones & Lamson's who have a projecting machine in which surfaces are photographed and their standard judged by cloud effects. That is the nearest I saw to any practical application of the idea. My own opinion is that the methods you have described

are too academical to be practical. Are you aware of the Jones & Lamson method?

MR. SHAW: I don't understand what you mean by cloud effect.

MR. WHITEHEAD: They used the reflection of the light in stages which gave them different effects for different surfaces. I was told that that was the nearest approach there had been to making it a practical job.

MR. SHAW: A variation of the reflected-light method is employed in Germany. Instead of using the bare light they pass the light through a grating and so get lines of light reflected on to the surface. The difficulty of the system is that when surfaces are nearly alike the diagrams do not tell which is the better. I have tried to make it clear that I have endeavoured to construct something useable in the workshop, opposed to what has been done in the States, where the apparatus has to be isolated in ideal conditions and can test small parts only. With my instrument I can test any surface you like to give me and provided that I have the materials handy I can turn out a contorogram in ten minutes. In the workshop you should easily get one in five minutes. The cost is merely that of the time and the photographic material. I certainly think the method capable of practical application in an ordinary workshop. I don't think you could call it academical.

MR. WHITEHEAD: What is your opinion of a steel cylinder with a bore finished exactly as a Johannson Slip? Would you put that as better than a cylinder well honed and afterwards lapped?

MR. SHAW: My paper mentions and expresses opinions on mirror finish. Mirror finish, *qua* finish, is superior to honed finish, but you can go too far and Johannson gauge finish is certainly not the best possible for ordinary running. For that purpose a matt finish is better, for this reason: Oil on a nearly flat surface can move but as a sheet, for the movement of any one particle is transmitted immediately to all the other particles, whereas on a matt surface each particle pushes the next which, however, being anchored in the material, is compelled to rotate and roll rowards its immediate neighbours, causing them to turn and roll and, through them, their neighbours, until every particle is a-rolling. No. Johannson finish is not necessarily the best.

MR. WHITEHEAD: I agree, in surface finish you can go too far.

MR. DANIELS: Right through the lecture the measurements referred to are of such extreme accuracy that I should like to know what assurance the speaker has that vibration does not enter. I cannot quite see how it is possible to exclude it altogether and to ensure that there is no chance of any vibration being recorded.

MR. SHAW: If I traverse my needle across an optical flat at a very slow speed and vibration occurs, instead of tracing out a thin line on the photographic film the light moves up and down

and so traces out a thick line. If I take half-an-hour in recording across ¼ in., with my motor running all the time, and get a thin line I know there is no vibration. Again, if I take four records such as shown in Fig. 8 it is hardly likely that vibration will cause the same error in each. On some records from the States of surfaces of a certain form with polished tops some of the lines are thin in some places and thick in others. That was possibly due to vibration. Actually if I hit my instrument with a hammer I get two little quivers of about ½ in. amplitude and then the movement ceases. The problem is to damp out movement that can be amplified. Slight vibration in the light system, for instance, has no effect as it is not amplified.

Mr. Mawer: Mr. Shaw has told us that he hopes in due course to produce records within five minutes, and states that he considers that this being so, the apparatus and method are practical. I submit that while they may be so from the research point of view, they would be quite hopeless from any practical production point of view because if you have a few thousand parts going through in the course of a day a good many instruments would be required; and not only that, you are only going to cover a line about ¼ in. long. Would it not be more practical to develop the instrument shown first, whereby you revolved the part under a pick-up? Thus it might be possible to take a gudgeon pin, revolve it, and watch a suitable millivoltmeter and get a reading straight away. This might be more practical.

Mr. Shaw: On production work, some firms inspect every piece, but others rely upon what is termed "percentage inspection." The latter would be the method of the contorograph. The primary object of this instrument is in the way of research, to determine the tolerable degree of roughness for given conditions. That discovered, the next step would be to find production methods to give you the desired finish, and those methods would be specified. You could then be sure that if the methods were strictly followed, the finish would be right. But it is possible for slight variations in procedure or tools (grinding wheels, for instance) to cause considerable variation in finish or, rather, in roughness, variations not visually discernible. Thus, though you may have standardised your methods, means for discovering incidental variations are imperative. But that does not signify the surface testing of every piece. You are producing, say, gudgeon pins. If, of every hundred, the first and last produced were right, you could reasonably assume all to be right. In effect you are applying the percentage system with more reason than to check dimensional accuracy, for finish is unlikely to vary so much as size.

Mr. Aust: With regard to the instrument shown in the first

slide, it is possible, I believe, to get a frequency response somewhere in the region of 16,000. Is that high enough ?

MR. SHAW : As I see it, the problem there is the calibrating of the instrument. You may calibrate to certain current conditions and then the instrument has to be transported half-way round the world, where you meet with entirely different conditions, necessitating re-calibration. Also, there is the influence of the mass of the object on the test. A thin specimen will tend to cause vibration. It is slight, but it is there. I am not condemning Harrison's method, but I must point out its disadvantages. Then, again, it does not give you the shape of the roughness which, I find, materially influences friction.

CAPTAIN BURGOINE : The article from *Machinery* passed round gives some figures for surface roughness. The roughness given for honing after boring is 0.0001 in., which seems quite a lot. How does that compare with the Johannson gauge block ?

MR. SHAW : These figures are for the specimens in a particular series of tests. They do not denote ideal finishes. In normal bored finish without any grinding you get a typical roughness of 0.00075 in. ; in fine-bored finish the roughness is 0.00025 ; in a typical honed finish, 0.000125 ; in mirror finish, 15 millionths ; and in Johannson gauge block finish approximately one to two millionths. In optical flats the departure from flatness is the most important item, and you do not worry much about scratches, for scratches only diffuse the light a little, whereas general departure from flatness distorts the light.

Discussion, London Section.

MR. DAVID CLAYTON (National Physical Laboratory): I have been venturesome enough to enter this field of roughness measurement and would like to raise some points which have occurred to me. My instrument, which Mr. Shaw has not mentioned, was described in *Engineering* in March of last year. I can congratulate Mr. Shaw on his device for getting horizontal distribution in his diagram without the trouble of a gearing system. It is very neat. My own apparatus has not got to the stage of being made autographic, as it was designed for a particular job and the expense was not justifiable; but I think I should certainly adopt Mr. Shaw's idea if I did make it autographic.

Another point, however, struck me when I was considering the autographic idea, in relation to the fine finishes I was concerned with, and I turned this refinement down partly because I decided I should have to go so very slowly over the surface; otherwise I felt that I should not get all the roughnesses. I think my records are all much rougher than Mr. Shaw's; in going over a surface I got ups and downs which he does not show. I wonder whether his speed was not too great with his dash-pot. It is not an important point, because obviously he has got the roughnesses which he wants and can repeat them; but I feel he has not got all the small irregularities. (Replying to Mr. Shaw) my magnification is greater—where you record 0.001 inch on your diagrams, I have got 0.0001 inch.

It would appear from this that it may be necessary to have different kinds of roughness-measuring instruments, according to the grade of finish. For the rougher surfaces something of the type of Mr. Shaw's Contorograph might be suitable, but I was interested in very fine finishes, though I have actually published records on coarser surfaces to show what the instrument will do.

I turned down the needle type of stylus because I felt that with a fine-enough point for fine finishes a round thing would not have sufficient strength; therefore I adopted a broken razor blade and put the edge at 45° to the surface being investigated. I thought that would give greater strength.

Very fine finishes, such as gauge finishes—an important subject which will appeal to you— I feel myself it may not be possible to test with any kind of pointed stylus. Mr. Shaw mentioned the Collin's system of lapping a cylinder and measuring the length and chord; I feel that something might be done in that direction, as a very fine polish may show up roughness when you get to the stage

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where the stylus will not get into the grooves. That method has actually been used for gauge finishes by Mr. Rolt of the Metrology Department of the N.P.L.

Another point that seems to me extraordinarily important, and Mr. Shaw has mentioned it several times, is the fact that if you plot these records to equal scales you actually get a curve that has very gentle undulations. If you think of the shape of grains of a grinding wheel, this result is not surprising. There is far too much speculation on the basis that the surfaces are actually like the horizontally cramped records. Mr. Shaw modified the irregularities somewhat in the corrosion diagram that he showed us, but they are still very sharp. I wonder whether the realization that they are not like that would alter his speculation as to what happens.

Another point is that I found, using my apparatus, that I did not need to cover a large piece of material. This was because within 0.02 in. or 0.03 in. the type of surface repeats itself very closely. That is, if I got a particular type of irregularity and a number of them followed, essentially the same shape would recur in a test at another position. I should say that I was not dealing with a honed surface, as I think Mr. Shaw was at times. I am quite willing to accept his statement that a longer record is required for such a complex surface. Mr. Shaw stated that from the look of a surface you cannot get another surface to correspond. I have found however, after I had gained some experience, that I could, by using a lens, estimate whether the roughness approximated to 0.00001 in. or to 0.0001 in. It was in fact not difficult to speculate as to what the range of variation was, but I quite agree that you cannot get any idea as to what the shape of the irregularity is. I think that with experience you *could* set up a visual standard for each type of finish.

One thing I did not understand from Mr. Shaw's description was how on an engine cylinder he could measure in the same spot again. It seems to me rather difficult to locate a large article like that sufficiently accuratoly to get repetition.

I was dealing with journal bearing lubrication and I found that it was fairly easy to get a smooth surface, but the trouble was to cut out the big-scale variation. I found the roughness on a macro-scale was much greater than that on a micro-scale. Mr. Shaw also dealt with this point in connection with lapping cylinders. I got, say, a major variation of 0.0001 in. amplitude when the minor roughnesses might be only 0.00001 in. As these major variations were to my mind important, I made an apparatus to measure the departures of the bushes from a true cylinder, without worrying about the little roughnesses. This supports Mr. Shaw's point that you should form the surface of the engine cylinder or the surface of the inside of the bush very accurately, first by some generating

system such as high-speed turning, using a very rigid tool, and then by just titivating the surface afterwards without spoiling its form. We found that high speed turning with minimum smoothing off gave a result far superior to that obtained when we left a fairly generous amount to be removed by lapping.

Actually you do come across these little roughnesses on the tops of the larger hills when starting or when failure occurs giving metallic contact. A fairly smooth condition, however, makes you wonder whether the tiny roughnesses are so awfully important in view of the particles that are circulating with the oil. The amplitude of the variations may be, say, 0.0001 in and filtering out 0.0001 in. particles is a tough proposition! In many instances, with particles circulating, the question of the roughness and wearing down of the irregularities is much less important than it may seem at first sight.

The graphite-treated oils seem to act by prolonging the running-in. The graphite preserves the form for a long time in comparison with the surface running with plain oil; and it makes me wonder whether it would not be better to get rid of these roughnesses, then change the oil and start with new, for Mr. Shaw got down to the same condition of smoothness eventually. I quite agree, in making that criticism, that the way the roughnesses do come away when you make contact does depend on the lubricant, but I feel that here we are really entering into the field of speculation. There are not enough facts as to what happens in the wear of the surfaces under these conditions. Much more information on the mechanism of wear is required.

I do not quite agree with Mr. Shaw in some points about journal bearing, formation of pressure films and so on. In one place he mentioned that shocks break down films. I do not agree with this at all. In pressure films the film is extraordinary resistant to shock.

Mr. Shaw: The essential difference between my instrument and Mr. Clayton's is that I was concerned mainly with measuring roughnesses met with in general workshop practice, surfaces used for bearings and other moving members, whereas Mr. Clayton is rather more concerned with the finer finishes such as appear on gauge blocks. His roughnesses are far finer than mine.

Now it is true that if you have a very slight roughness as on the sides of general roughnesses, the very smallest of these may not show on the contorogram because of the retarding influence of the dashpot. There is some lag that you cannot avoid, but when testing a very smooth surface and I want to get the very small roughnesses, I can put the dashpot out of action. One has, however, to be careful not to get vibration.

Mr. Clayton's magnification (10,000) is about twice mine at its greatest, which is about 5,000. Normally, 2,000 magnification

suffices for most of the roughnesses with which I am concerned. Admittedly, the razor blade is sharper than my needle point and will detect the ultra-small roughnesses. Actually, if necessary, I could adopt the blade principle.

Considering corrosion I pictured in my diagram the effect of the whole of these hills falling away and I think that I mentioned that I pictured them as falling away evenly throughout for convenience of explanation. In an actual surface you get gradual undulations, but, as Mr. Clayton says, you get small roughnesses on the undulations, and it is if these small roughnesses that the corrosive substance collects. Small particles so loosened circulate with the oil and tend to rip out more particles. That, again, brings us to the point Mr. Clayton mentioned as to prolonged running-in for, if you are running-in quickly to save time, say, the small particles and those that come out in the running-in, mix with the oil and continually circulate, tending to scar the surfaces and still further roughen them. These diminutive particles are not easily restrained by the filter, so that if by using graphite you can make the wear more gradually, though you may prolong the running-in, you are preventing the fouling of the oil by wear inducing particles. Mr. Clayton wonders whether the small surface roughness is of moment when we consider the particles circulating with the oil. May I wonder where the fine particles of greater size than the surface roughness come from if they do not come from the surface.

Now, actually, in my tests I have found that though you have, say, double the roughness on one surface than on another, you do not get merely double the wear during your running-in, but far more. It is these small freed particles that are causing the greater wear, so that the smoother the surface is the less it will wear. A small length only of a very smooth surface need be tested on the contorograph. In the diagram I showed of the fine boring probably an eighth or a tenth of the length would have shown the character of that finish, the rest being but repetitions.

Now this problem of replacing a cylinder in the same position. You cannot of course re-locate from the outside of the cylinder and trace over the same spot, so the method I adopt, if the specimen is small, is to scribe two fine lines on the surface where they will not be affected during later treatment, and then arrange so that the needle will swing from one mark to the other. When testing a cylinder bore I lightly mark the end face at each end of the bore. Then I take a piece of transparent paper or thick Cellophane and mark it to correspond with the cylinder marks. I make a hole in this piece of paper at the point where I wish to test the surface, make two marks on the edge of this hole and traverse my needle from mark to mark. I complete the test, remove the block, and when the block is returned to me for testing after running I have

merely to locate the paper in the bore as before so that the needle passes between the same marks.

Generally when the boring marks go round the bore an error in positioning makes a very slight difference, not as much as might be imagined.

If you have perfect bearing and journal surfaces, the imposition of a load may not break the oil film, but when the surface is broken up by the roughness its area is considerably less; and I maintain that you do get at times metal to metal contact. Not, of course, if the oil suffices to form a thick film, but when it is scanty. Even if there is not actual metal-to-metal contact the wear is greater than would be expected from a full oil film. It has been proved that when this occurs the wear is less when there is a protective graphoid skin,

MR. WEBSTER: With regard to the matter of colloidal graphite I would like to support Mr. Shaw. Some years ago it was my pleasure to conduct some tests on motor-cycle engines and it was just at the time when graphited oil was in its first form. Those were the days when you got black sludge in the bottom of your crankcase as there was difficulty in suspending the graphite in the oil. The first engine tested with colloidal graphite was run for several hours on various tests and finally a destruction test was made. The wind fan was first stopped (it was an air cooled engine), the oil was then run out, but the engine continued to run. The raised temperature caused the high tension wire to be burned through but the engine still ran owing to the plug becoming overheated and preigniting. Finally the engine stopped, the big end "went square," the piston seized and so on, but the fact that the engine did run under such exacting conditions is eloquent evidence of the advantage obtained from the graphited oil which had impregnated the bearing surfaces with graphite.

MR. SHAW: Mr. Webster's remarks on running-in his motor-cycle engine are interesting and certainly bear out certain of our discoveries. Normally before the engine seized you would have gone into the next garage for fresh oil.

I have just remembered a point of Mr. Clayton's. Mr. Clayton spoke about the roughnesses on the sides of general roughnesses. Now I have two fine-turned specimens here, rather worn by handling, but contorograms show approximately the same roughness. If you compare them carefully you will see that one has a somewhat matt finish and that the other is fairly well polished. The finishing method was precisely the same, but for one a straight mineral-oil cutting solution was used and for the other a graphited oil. The graphite has not actually altered the measurable roughness, but the finish is brighter. I presume that this is due to the fact that whereas on the one the roughnesses on the undulations are but slight on the other they are bigger. Slight differences in the roughness on the undulations are, on account of the foreshortening of the contorogram, not noticeable.

Mr. A. J. Aiers : To-night's lecture has mainly dealt with the special finish of cylinder bores, and is not applicable to general finishes. In speaking of one of the slides shown Mr. Shaw mentioned the various lobed surfaces made in a cylinder bore and how it might help lubrication in a bearing. He did not, however, mention a point put forward when fine-borning machines first came out ; namely, that instead of a smoother surface they left a fine groove which acted as a storage for oil and therefore lubricated the surface.

On the next slide he showed various contours which he explained were magnified and which have been mentioned before to-night, but if these were drawn to scale, you would only have very shallow valleys in relation to the distance between the curves, but which, the slides being exaggerated, showed as high cliffs. If we imagined it in its real shape in such a very slight contour the effect shown could not exist. A rolling tool would not, therefore, have the effect shown. The point was excellent in that it showed the reason for not bringing back the old type of rolling tools ; but we do know that the machine shops at the present time use rolling tools, and obtain well finished surfaces, which stand up to their job.

He also showed various lapped surfaces with an almost perfect contour, and I think it is a fact that you could take such a surface and lap it using the usual polishing medium, some kind of oxide. You probably think you have produced a perfect surface, but you have not really eliminated the hills and brought them down to the level of the valleys. All that you have done is to smooth them over, because you could etch them with acid and reveal your previous marks.

Dealing with that point, I think it probably explains some of the reasons for colloidal graphite giving such good results. Is it because it does tend to smooth the metal and roll it over until the valleys are filled with amorphous material ?

I ran some motor car engines with and without graphite, mainly to see what time could be saved and whether it produces better surfaces. We ran one under proper test conditions with electric machines, but on the usual six hours of running-in we could not show any material saving. I agree that the surfaces looked very nice when finished, but time was not saved in that instance.

The lecture was to deal with roughness of surface, but I think that it should have been smoothness of surface. We hear of these small amounts corresponding to the thickness of two atoms, the surfaces being polished so much that you dare not handle them for fear of spoiling them. I agree that we should train our draughtsmen to put various finishes on drawings, but we could not go to heavy expense and trouble in the ordinary

finishes. It is all very well for special bearings and things of that nature.

I was hoping that the lecturer would have mentioned something about rough surfaces and not superfine finishes, and whether he would recommend visual inspection.

MR. SHAW: A very strong point of believers in fine-boring is that the spiral groove, as they term it, admirably retains the oil. Well, maybe it does, but when you consider that recent research—perhaps not too recent either—shows that when you get a film two or three millionths thick you have got full fluid conditions, well, I rather doubt whether you need the tremendous groove, comparatively speaking, that the fine-boring gives, for even the slight roughness of the smoothest surface will retain sufficient oil to form a film so thin.

Now this rolling over picture I tried to impress upon you was not the precise thing. I would not like to say what the real action is, but I tried to make it clear that you do not get exactly what I pictured as hills rolled completely over and this only if the rolling pressure is heavy and you get an obvious roughness. Precisely what is the effect I should not like to say; but what I did was this—I took a finish which gave a certain record and a burnished surface with rather a similar roughness. These were thoroughly cleaned and the burnished surface dipped into slightly acid liquid, thoroughly removed, washed clean to remove all traces of acid, and then protected by oil. First of all a record was taken and then the specimen was immersed in oil for a considerable time, care being taken that the atmospheric conditions were such as would cause corrosion. Then the specimen was thoroughly washed in ether, inverted, and rapped. Another record was taken and this showed that the rapping had ejected very minute particles. However thoroughly the washing was carried out it would not remove any corrosive material trapped in very small concealed pores, for they have capillary action. In a similar test carried out on the ordinary finished specimen small pieces were not loosened by corrosion.

Now rolling or burnishing produces hard surfaces, and these have better wearing properties than an ordinary finished surface. That may be partly due to the better finish, but it will be due also to the formation on the surface of what is known as the Beilby layer, a surface condition induced by running or even by burnishing. The surface structure changes from the ordinary crystalline to the amorphous form; and research has shown that the surface, while harder than an ordinary surface, is actually less dense, and it is because of this lower density that it holds or adsorbs or stands a better chance of holding or

adsorbing oil, so that during the subsequent running you get more intimate adsorption of the oil by the surface than in the initial running. Lapping does not completely remove the roughnesses, but rather pushes them in; but to some extent it depends upon the lapping pressure.

Now, as to the point that you did not get benefit from your six hours' running: I have not claimed that you reduce the running-in time, but I do say that you reduce the risk of seizure and wear and improve the surfaces; and I have never claimed that nor do I purpose claiming that you would ever reduce the running-in period, unless by cutting down the risk of seizure you were able to run at higher speed under greater loads. Actually certain people find that when they use graphite the running-in may be more vigorous. It does take a certain time to form this graphite surface so that if you run-in for the first six hours you will find that you will not get either an increase in the power output or a reduction in the power required to turn the engine (if you measure that way). You will get benefit later, but I think six hours' running is not enough to find the full benefit. I recently analysed a series of tests carried out, and during the first hour's running not much gain was shown. Actually no gain seen was other than that you might get by experimental error, but during the complete running, that is, after many hours of running, the gain was evident. In short, you get slightly higher power output, and less power is needed for motoring.

I have here to-night two samples showing the finish you get on running surfaces. They are typical finished surfaces. Whether the finish is for running or merely for appearance, it is, I think, necessary to find with the contorograph what finish you are getting by certain processes and then to select that process which gives the desired finish. That is, you find first of all that certain materials, certain grades of wheels, certain speeds, and so on, give you a certain finish. Then you say, for such-and-such an object you require such-and-such a finish, and that to get that finish you must adopt certain methods.

If your rate fixers or other officials say that if you do this the price for the job will be increased, I can only suggest that you ask for an increase in the price. The problem is to find methods that will give the finish stipulated and use the methods. If economic considerations rule them out, then they are ruled out.

Mr. B. H. Dyson: In opening remarks the lecturer indicated that modern industry demanded scientific definitions and standards, such as defining by degrees the temperature for heat treatment and that by controlling the treatment to this known standard, the vague method of heating to a "cherry red" has been superseded.

I should like to ask Mr. Shaw what standards of unit measurements for inspection or comparison have been devised and, secondly, what symbols are used to indicate the finish required for any surface. For instance, we no longer use the hit-and-miss methods of using a file on a hardened block and then assume the degree of hardness; we indicate by a definite symbol, the brinell or scleroscope number, the state of hardness required, and control and check by this standard to arrive at and maintain consistent results. I believe that in Germany certain symbols are used to denote certain finishes. I do not know whether they are recognised standards representing a specific state and class of finish, but I am rather interested to know, as these seem essentials to the development of surface finish on a scientific basis.

MR. SHAW: Symbolisation as distinct from the familar "f," "ff," "rf," and others has developed chiefly in Germany, but to a great extent in the States. In some of these the symbols are little squares, triangles, circles, and these combined. They are more or less the highway code of surface finish and save time and paper. But ideas of finish differ, so in addition it is suggested now that, say, the depth of the hills of the roughness in millionths of an inch, say, 200, 300, 450, or what might be deemed suitable, should appear. And one might also specify the area of contact when the hills have levelled off by a certain amount.

Your technical or design engineer having by his symbols indicated his requirements, the works could then say, "Well now, to get that finish we must follow this procedure, run at these speeds, apply these feeds," and so on, procedure known by experience as capable of giving the specified finish, or to be determined experimentally.

MR. GROOMSBRIDGE (Section President): We have listened to the paper and have seen slides of apparatus specially designed to enable one to determine the finish of a surface, but it seems to me that we are still in the hands of the inspection staff who have to use their own judgment, as the actual instrument shown could not be used on the shop floor. I was hoping that we should hear of an instrument that could be put right on the job and in some way assess the quality of the finish, but it would appear that we have not reached that stage of perfection yet.

MR. HAZLETON: The reason I am proposing this vote of thanks to Mr. Harry Shaw is that I want to thank him not only on behalf of the London Section for coming here from Manchester and giving us this lecture, but on behalf of the Council of the Institution for the fact that he has given it to no less than eight of our other local sections as well. We owe a debt of gratitude to Mr. Shaw for the time, trouble, and expense that he has undergone in giving this lecture to so many of our local sections. It is a tribute to our younger members, especially our graduates like Mr. Shaw, that they are coming forward

in increasing numbers to take part in the lecture activities of the Institution.

MR. SHAW : I thank Mr. Hazleton for his remarks and I can assure him that since I started giving this lecture to the various sections I have had to modify considerably my original thoughts on it. For if a criticism is raised it is raised with reason and though at first the lecturer may think that the speaker is speaking with perhaps less intimate knowledge of the subject, when he has received the same criticism two or three times he realises that either it is justified or that the presentation of the matter is such as to mislead and so justify the criticism. For instance, at one of my early lectures it was suggested that this instrument was not suitable to take into the works. Now personally I feel that provided that sufficient precautions are taken it is quite clearly a portable instrument, and that you can take it into the works and your working conditions will not interfere ; but I am forced to admit that before the workshop will adopt these methods of measuring roughness it is essential to devise and construct a far more portable instrument. I am trying to work on that at the present moment and I have found, the further I study it, that to construct that workshop instrument it is necessary to depart considerably from the present pattern. Some things can be retained, but photographic recording must be abolished. It is too slow a process for the works : and so I hope that Mr. Clayton will think about the problem and see if he can devise what I have been trying to devise. I will give him a thought that may be of use, and that is to arrange for the movement of the point of light reflected from the mirror to control, through photocells, the movement of slides and to move a pen on paper and so trace out the roughness direct on the diagram. To some extent I have solved the problem, but there are elements in it that are more suitable for the electronic specialist to tackle, one being to get rid of the lag that still exists in such devices.

RETROSPECTION AND INTROSPECTION.

Section Presidential Address, Birmingham Section, by E. P. Edwards, M.I.P.E.

IN assuming office as President of this Section earlier than I should have done had it not been for the untimely death of Mr. Garnett, I feel that I have not yet served that probationary period which experience and a lengthening line of illustrious predecessors demand. You have been fortunate in your choice of previous presidents in that, to a man, they have not only been qualified to speak to you with authority, but have also possessed that flair and ability which has enabled them to impart their thoughts and ideas in a practical and engaging manner. I can lay no claim to such accomplishments, and perhaps, like many of you, whilst happy in individual conversation and interchange of ideas, become appalled when faced with the prospect of having to make a public, or semi-public utterance.

When I first joined the Institution in 1927, there was a small but gallant band of men determined to make it a success. It was their enthusiasm which prompted me to accept the vacancy on the committee, and I am proud to have been associated with them in their efforts, because you will, I am sure, concede that they have been successful. We have more members now, in the Birmingham Section alone, than existed in the whole Institution, ten years ago.

I notice that Mr. Youngash, in April, 1932, during his presidential address told us that the membership at that time was nearly 800, and that he had little doubt that we should still progress. We are now nearly 1,400 strong, with an annual income of over £3,000, which can certainly be claimed as substantial progress. What is more important still is the increasing recognition being given to this Institution by Government Departments, large industrial concerns, and other institutions, who do not feel it derogatory to ask for our opinions and advice.

Looking backwards for a while, it is amazing to think of the influence which the engineer, judged in the widest sense, has played in the advancement of civilization, and what he has achieved, often in spite of the most strenuous opposition. You will all recall the accomplishments of Stephenson, Watt, Telford, and other great pioneers who, with the comparatively poor material at their disposal, achieved so much to improve the lot of posterity. With the march

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of time has come a more organized development, fostered largely by international competition and the needs of peoples, expanding not only in numbers, but also in ideals.

Consider the comparatively lengthy time taken by our country to make the advancement that has taken place in, say, Japan in two decades, or Russia in one. True, these countries still have a thorny path to follow before approaching our ideals, but it is significant that both of them have attempted to lay down their foundations on sound engineering principles. We now have the anomalous position, that these tyro's, if I may so call them, are not only contemplating, but organizing production in all spheres in vaster quantities than were dreamed of in this country but a few years ago.

It remains to be seen what effect the immense production potential of these countries may have on the world in general, but certainly Japan, comparatively small in area, but dense in population, and largely for this reason, is already a competitor in the world's markets, although more in the textile than the engineering field. On the other hand, Russia is a country of such vast proportions, with almost unlimited natural resources, having a population of 150,000,000, the great majority of them in the past without even the most simple necessities of life. Imagine what production means to them—what the pioneer work of production engineers in other parts of the world in the past, means to Russia in the future. Already vast production units on a scale formerly undreamed of are helping to make everyday life there more tolerable. We may or may not agree with the political form of their Government, but admit we must that living conditions in Russia are advancing at a rate never before equalled in the history of civilization.

Engineers well known to me, who have been making business trips annually for some time—I cannot unfortunately, speak from personal experience—bring back information, unbiased and unvarnished, of the great achievements there. Yet, even they admit that the production potentialities are merely scratched, and that many years must elapse before the conditions of life approximate to that of this country. Summed up in a few words—while the production possibilities are enormous, it will be a very long time before Russia can enter into the world's markets in a competition capacity.

It has been said by many writers that the Great War was responsible for a new conception of production, and while this may be true of the majority of commodities, it must not be forgotten that Lancashire at one time had organized production, which has only been eclipsed and fallen behind by comparison with our more advanced ideas. Here undoubtedly, there is room for a fresh and virile organization of production, with the dead wood and prejudices

cut away. Railways, which have certainly shown a commendably freshening outlook during the last few years, still have some distance to go before they can be considered to be in line with modern ideas. Mining, and the manufacture of steel, also require revision, and here again the production engineer should find a field for his activities. It will, I believe, be admitted that the actual manufacture of steel is not as advanced generally, at least in this country, as the purely metallurgical and research side of the industry. I am well aware that this condition has been largely brought about by economic conditions, which certainly are not under the control of the production engineer, although he may, in course of time, exert considerable influence upon them.

I am not proposing to more than remark on the incidence of production in the motor car and allied industries, although some of my friends in this room, who are thus engaged, might express satisfaction or dissatisfaction at the progress made, according to their particular outlook, but it is certainly one of the industries where a broad vision by a few people has brought unparalleled results.

The gas and electrical industries have also made considerable progress, which even now is being refurbished, and I am sure we shall see much progress here in the next decade, particularly as there is a very lively competition between them. Some papers we have had in recent years have dealt with food preparation and packing, and illustrated the great scope still open for organized production and distribution in these fields, which after all, have the widest possible market, and the most universal interest. The latest entrant into the production field is the aeroplane, and although we may well deplore the political activity which has necessitated the military view-point, the civil side of aviation is also making an important contribution to our daily life, and both open up great possibilities for the production engineer. Lastly, the machine tool and small tool trades are now organised on a basis of production never thought of before the necessities of war made it imperative.

To-day, it is quite a common sight in our supplying organisations, to see line productions on complete units such as gear boxes, spindles, beds, etc., followed by sub-assemblies and final assemblies, and even testing and inspecting on that much abused but descriptive term—mass production.

I well remember in my very early days being connected with a firm of world-wide standing who had to make their own production machinery, and the individual manner in which these machines were built, Tom building one type completely, and Bill another—collecting the parts from various machine sections and assembling them, often waiting long periods in between times before any progress could be made, would to-day be considered ludicrous, and yet, in its time, this was a " modern " works.

While on the subject of machine tools, a few thoughts concerning their use and users may not be out of place. I often hear it said that machine tool makers do not keep pace with modern conditions, but this, I believe, is very largely a fallacy, and as one engaged in their development and sale, I would suggest that the user is more often the one who is at fault. Offer him something new in construction, or revolutionary in design, and despite the fact that you may already have spent enormous sums of money, and expended hours and possibly years in research, labour, and test, the usual attitude is: "I don't think it will be better than so-and-so's, which I have used for years"—or, equally encouraging: "I can't see how it will benefit me because I don't expect it will do what you say"—"Anyway, who is using it already, before I do anything with it?" and perhaps finally: "Well, I'll install it entirely on approval at your expense!" In desperation you accept the latter condition, and later on the same man will proudly exhibit his new and up-to-date machine, and ask its admirers to applaud his perspicacity and foresight.

There is also the case, somewhat analogous, of, say, an improved attachment to an existing machine. Here, despite the fact that its adoption may mean an increased and continuous profit to the purchaser over his existing methods, the attitude is often: "Why didn't you think of this in the first place?"; or "The price is too high—it is only a few bits of cast iron and steel—you must be making an enormous profit out of it." The actual fact is that the maker gets one profit—if any—while the user possibly makes thousands per cent. out of his investment. I have a case in mind where the price of an improved attachment, which effected an immediate saving of not less than 50%, priced at £75, always brought forth sarcastic comments about profiteering, whereas the facts were that the makers had spent three years and several thousand pounds in experimental work before the object was achieved. This initial work is rarely, if ever, given consideration by the purchaser, although often it is the most serious and heaviest part of the ultimate cost.

In defiance, however, of existing conditions, there have been enormous developments in machine tools even in the past ten years, and doubtless the same sort of progress will continue. I would, however, appeal to those whose duty or privilege it is to instal new plant, to give consideration to the points that I have just stressed. As an encouragement I would remind them that without exception, those firms who have had the broadest vision and been progressive with regard to plant replacement and renewal, are to-day the outstanding successes, while those who allowed things to lapse, soon went out of business when the late depression set in. With possibly one exception, occasioned by faulty finance,

does anyone present remember a plant being sold up where the machinery and equipment could be considered efficient and up-to-date ? I venture to say that the answer is No.

In this connection it may well be remembered that ultimately the cost of labour forms the major part of the cost of most things, and any effort to reduce this, not by getting more foot pounds of work out of the individual worker, but rather by improving his equipment and thus producing more useful work for the same effort is bound to be beneficial to the general community, because the cheaper and more accessible things become, so much more can they be enjoyed by a greater number. One of the greatest modern fallacies is the talk of over-production and saturation point of commodities. This point can never be reached until every living person has sufficient to satisfy, not only their bodily needs, but also their mental and recreative requirements, and history will continue to be written for a very long time before this millennium is accomplished. That there is mal-distribution of the worlds production must unfortunately be admitted but without doubt it is by increasing the productivity, decreasing the relative cost, and thus widening the appeal for natural and manufactured goods, that the problem of distribution will eventually be solved. Apart from the needs of our own peoples, for more and better goods, think of the vast potential markets in India, Asia, and other parts of the world for those things which are commonplace to us.

We have all been at some time or other inspired by the imagination and pre-vision of others. How often has fiction become fact. Jules Verne and his " Twenty Thousand Leagues Under the Sea " have become the modern submarine, almost identical with the original conception. Edward Bellamy gave us several remarkable peeps into the future in his " Looking Backward," one of which comes vividly to my mind. Although written about 1880, but imagining life in the year 2000, he describes how, not feeling like venturing from the house, he pressed a button in the wall and flooded the room with music, then being played by the Queen's Hall Orchestra. Even he, however, did not visualise that this might equally well be the Berlin Philharmonic or the Philadelphia Symphony Orchestra. This seeming impossibility then is such a commonplace to-day, that it excites hardly any wonder in our children's minds. We have adventures in the stratosphere, formerly fiction, now fact. To-day, we machine metals at 400, 800, or even 1,000 feet per minute, and yet the older ones amongst us can easily remember when they would have been inclined to scoff at the idea. Who is to say that in the future power may not be universally distributed by wireless waves, or that machinery, not yet dreamed of, will shorten man's working day and give him greater freedom

and leisure? Who would dare suggest that the Wellsian theories of to-day may not be practice in the days to come?

Think for a few moments of the achievement of the past few years in the field which affects us as Production Engineers. Oxy-acetylene, and oxy-hydrogen Cutting to almost precision limits, diamond turning and boring, plunge-cut internal grinding, entirely automatic. Pre-selection of feeds and speeds and push-button control on machine tools, centreless lapping, surface broaching on large parts like cylinder blocks, the use of photo cells, solenoids and pneumatic devices for automatic sizing, starting and stopping machinery and like operations, hydraulic traverses, and control of spindle bearings giving closeness of fit formerly considered impossible, gear cutting, finishing and testing methods, which have vastly improved the quality and life of gears, however imperfect these may still be. Magnetic chucks, which are wonderfully efficient and independent of electricity for their use. These are but a few which come to mind—doubtless you can think of many more, but they all show that there is no standing still; invention and progress are inevitable.

Mr. Field, in his presidential address two years ago, visualised the time when their might be a Director of Production with a seat in the Cabinet. I see that to some extent this has already become a fact by the announcement from the Air Ministry of the appointment of a Director of Production—Air Ministry. The necessity for such an office is at once apparent and doubtless will be followed by similar appointments in other Government Departments. Let us hope, however, that production engineers as such may never become politicians and thus lose their detached and independent outlook.

Before closing, I should like to say a few words on a subject which is of vital interest to all of us—the future of the Institution. Its continuing success and expansion primarily depends on the active interest taken by Members, Associate Members, and Graduates. It is not enough to attend our meetings and leave matters in the hands of the sitting Committee, or of the Council. Life is transient, and like the human body the corporate body constantly needs new blood and a revitalising of its energies. It is up to each in his turn, and according to circumstances, to take part in furthering the growth and aims of the Institution. For the older members, and particularly those with experience, there is plenty of scope. Some may work on the Committee or, because of their specialised knowledge, render valuable service not only to the Institution, but to the whole community, by taking active part in the work of the British Standards Institution, it being certain that their connection with production engineering will make them peculiarly suited to give help and advice in this direction.

There is a constant need for the preparation of new papers on subjects connected with or allied to the science which we exist to improve. For those who cannot undertake this, there is the taking part in discussions at our meetings, because often what may be ordinary and obvious to one, may be invaluable information to another. Production engineering covers such a vast field, that the cleverest and most experienced amongst us can only hope to specialise in some branch. Lastly, there is our duty to the Graduate Members, those who are on the threshold of their career and who, in a few short years, will not only take our places in the world's business, but also carry on the work of this Institution. Our responsibility to them is two-fold, first to assist them in their work, and make intelligent use of them in our businesses whenever possible, and secondly, to assist in their training by such help and guidance that it may be individually and collectively in our power to give.

This is a subject particularly dear to the heart of our friend and wise counsellor, Mr. Groocock, and I know he will forgive me for making reference to suggestions which he laid before the council meeting held in London recently, and which were unanimously accepted. Briefly, they are for a series of special papers, covering a period of three years. For the first year the subject will be "What the Graduate Should Know," to be given by lecturers, some of them connected with the teaching profession, but the majority to be given by men who are able to indicate what they would expect from our Graduates in business and technical ability.

For the year following there is to be progression to "The Graduate's Place in Production," the papers to be given by members who can give practical indication of how our Graduates can be used in their own or similar organisations, and for the last year, "The Graduate and Management." These must of a necessity be given by those having managerial experience, not necessarily members, but men fully qualified to talk with authority on such an important subject.

I have only referred to the general framework of the scheme, as more will be heard of it officially, my object being to enlist the help and support of those of you who are qualified to assist in this important step.

To the Graduates themselves, I would say that above all others, the future lies with you, and while the Institution has a mission to fulfil on your behalf—I believe it is the most important of all its work—it should be your pride and provilege to carry on the work in future years, in a manner which will place the Institution in a position of paramount importance to production engineering in particular, and posterity in general. To you I would say that there is every sign that an era is commencing which will give you unparalleled scope and opportunity—unless this is interrupted by

international political and economic suicide—and I trust that as the years go on, you will, one and all, profit by your attachment to the Institution.

In closing I would like to pay a sincere tribute to all the members of the Birmingham Committee who have loyally supported me during the past session. It is no small matter that they give freely of their time and energy, and without men who are prepared to do so, the work could not be carried out so efficiently.

I would also like to make special reference to the energetic manner in which the Hon. Secretary, Mr. Burke, has carried out his duties. Mr. Burke, at my request, stepped at very short notice into the breach occasioned by the departure of our late secretary Mr. Steer, to take up an appointment in Australia. It is not until one occupies the position I now hold that it is possible to realise the immense amount of work which must, of a necessity, devolve upon the secretary, and although I know him to be a busy man, he has been of invaluable help throughout the session, always courteous and ready. I feel sure I am only voicing your own feelings when I thank the Committee and the Secretary most sincerely for their work on your behalf.